EFFECT OF FOLIAR APPLICATION OF GROWTH REGULATORS AND NUTRIENTS ON FRUIT RETENTION, YIELD AND QUALITY OF ACID LIME

(*Citrus aurantifolia* Swingle)

M.Sc. (Hort.) Thesis

by

YAMINI SAPAHA

DEPARTMENT OF FRUIT SCIENCE

COLLEGE OF AGRICULTURE

INDIRA GANDHI KRISHI VISHWAVIDYALAYA

RAIPUR (Chhattisgarh)

2020

EFFECT OF FOLIAR APPLICATION OF GROWTH REGULATORS AND NUTRIENTS ON FRUIT RETENTION, YIELD AND QUALITY OF ACID LIME

(*Citrus aurantifolia* Swingle)

Thesis
Submitted to the
Indira Gandhi Krishi Vishwavidyalaya, Raipur

By
Yamini Sapaha

In partial fulfilment of the requirement for the degree of

Master of Science
in
Horticulture

(Fruit Science)

Roll no. 120118274 **ID No. 20181930032**

2020

CERTIFICATE – I

This is to certify that the thesis entitled **"Effect of foliar application of growth regulators and nutrients on fruit retention, yield and quality of acid lime (*Citrus aurantifolia,* Swingle)"** submitted in partial fulfilment of the requirements for the degree of "**Master of Science in Horticulture (Fruit Science)"** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, (C.G.) is a record of bonafide research work carried out by **Yamini Sapaha** under my/our guidance and supervision. The subject of thesis has been approved by Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma certificate course. All the assistance and help received during the course of the investigation has been duly acknowledged by her.

Chairman

Date : 23/10/2020

THESIS APPROVED BY THE STUDENT ADVISORY COMMITTEE

Major Advisor & Chairman	**Dr. Vijay Kumar**	____________
Co-Major Advisor	**Dr. A.D. Huchche**	____________
Member	**Dr. G.L. Sharma**	____________
Member	**Dr. Alok Tiwari**	____________
Member	**Dr. R. R. Saxena**	____________

CERTIFCATE – II

This is to certify that the thesis entitled **"Effect of foliar application of growth regulators and nutrients on fruit retention, yield and quality of acid lime (*Citrus aurantifolia,* Swingle)"** submitted by **Yamini Sapaha** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.) in partial fulfilment of the requirements for the degree of **Master of Science in Horticulture** in the **Department of Fruit Science** has been approved by the external evaluator and Student's Advisory Committee after oral examination, under the chairmanship of head of the department.

Date: 28/11/2020

Signature of Head of the Department

(Name Dr. Vijay Kumar)

Major Advisor ____________________

Co- Major Advisor ____________________

Dean/ Dean Faculty ____________________

Approved/ Not Approved

Director of Instruction ____________________

ACKNOWLEDGEMENT

First of all I express my deep sense of adoration and prostrations towards the omniscient and almighty God for giving me this opportunity of doing M.Sc. Horticulture (Fruit Science). With immense delight, I take it as my proud privilege to express my profound sense of gratitude and thanks to my major advisor and chairman and Co major advisor of my Advisory Committee ***Dr. Vijay Kumar,*** *head of dept. in fruit science College of Agriculture, IGKV, Raipur and Co-major advisor* ***Dr. A.D. Huchche*** *Principal Scientist of horticulture ICAR-CCRI (Central Citrus Research Institute) Nagpur (M.H.) for constant inspiration and encouragement during the course of investigation and in the preparation of manuscript in spite of his busy schedule.*

*At this moment of accomplishment, I would like to express immense pleasure and respect to members of my advisory committee Dr. G.L. Sharma, Professor, Department of Fruit Science, Dr. Alok Tiwari***,** *Department of Soil Science & Agricultural Chemistry Dr. R.R. Saxena, Professor, Department of Statistics, Mathematics and Computer Science for their admirable guidance during the period of this research work and course of study.*

I have been very privileged for the facilities provided by Dr. S.K. Patil, Hon'ble Vice Chancellor, Dr. O.P. Kashyap, Dean, College of Agriculture, Dr. S.S. Rao, Director Research Services, Dr. M.P. Thakur, Director of Instructions Dr. G.K. Shrivastava, Dean Students' Welfare, IGKV, Raipur during the course of my studies.

I pay my sincere thanks to Dr. Vijay Kumar Professor and Head, Department of fruit science, Dr. A.D. Huchche principal Scientist of horticulture ICAR-CCRI (Central Citrus Research Institute) Nagpur (M.H.) and Dr. A. Thirugnanaval Scientist of horticulture ICAR-CCRI (Central Citrus Research Institute) Nagpur (M.H.) all the scientists and faculties of the Department of fruit science viz., Dr.G.L. Sharma, Dr. G.D. Sahu, Dr. Hemant Pangrahi, Dr. Deepti Patel and Smt. Smita Bala Rangarre and their excellence guidance and valuable suggestions during course of investigation and providing necessary facilities.

I would like to express my sincere gratitude to Dr. Madhav Pandey (Librarian, Nehru Library, IGKV, Raipur) and Shri U.K. Watti and all other members of the Nehru Library for giving me their kind help during the study.

I am extremely thankful to my loving and caring seniors Ashish sir, Debashish Hota sir, Anup V. Tatewer sir, Chaitanya Kholkute sir, Devendra sir, Dinesh Rathod sir, Anand K. sir, Sanhita V. Malvi Mam, without whom I would never have got my academic and research achievements. I also thanks to my batchmates Rajnish Sahu, Deepak Yadav, Akash pradhan, Pratibha khute, Swati Shukla, Pooja, Sukalu sir, Nidhi, Varsha Verma, Varsha Minz, Rajni, Asnath (Dolly) Gulshan sir and other batchmates for their mental support and help during study as well as research work.

I express my heartfelt thanks to my senior Ashish Dhongade Sir, without his support and guidance the completion of my thesis was not possible.

I would like to convey my cordial thanks to Sagar Bhaiya and others for helping me during the field work.

Attachment with some special persons makes the life more beautiful and exciting. I am very lucky that I have some true persons like Smriti, Bhargav, Tamraj, Himalaya, Swati, Nehal, Kala, Kirti, Jaggu, Rashmi, Pratibha, Jharna. They remain always very close to my heart and shared my all bright and dull phases of life with lots of smile, love, affections, support and encouragement, which always inspire me to go ahead.

It is the drop in the ocean of words that can never reach its mark to acknowledge infinite love, blessings, sacrifices, devotion and constant encouragements of my Dady (Mr. Kishan Sapaha), my mother (Mrs. Pramila Sapaha) and my younger brother Nilkamal Sapaha have been the sole source of inspiration for me to proceed ahead in my life and taught me to fight the battle of life. What I am today is also the result of love, belief and encouragements of my family, who always support me to be strong and face all the problems of life. I am lucky to take this opportunity to dedicate this work to my beloved parents.

At last but not least, I am thankful to the almighty GOD for all the blessings bestowed upon me and because of which, I am at this position today.

Department of Fruit Science *Yamini Sapaha*

College of Agriculture

IGKV, Raipur (C.G.) *Dated:*

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LIST OF NOTATIONS

Notations	Descriptions
%	Percent
^0C	Degree Celsius
cc	Cubic centimetre
cm	Centimetre
df	Degree of Freedom
et al.	And co-worker/ and others
Fig	Figure
ha	Hectare
i.e.	That is
kg	Kilogram
m^2	Square meter
mm	Millimetre
q	Quintal
viz.,	Namely
/	Per
<	Less than
>	More than

LIST OF ABBREVIATIONS

Abbreviations	Descriptions
ANOVA	Analysis of Variance
BR	Brassinosteroids
CCC	Chlormequat chloride
cv	Cultiver
Fig.	Figure
GA_3	Gibberellic acid
KNO_3	Potassium nitrate
H_2PO_4	Monopotassium phosphate
JA	Jasmonic acid
MeJA	Methyl jasmonate
NADPH	Nicotinamide adenine dinucleotide phosphate
ppm	Parts per million
RBD	Randomized Block Design

THESIS ABSTRACT

Title of the thesis	:	Effect of foliar application of plant growth regulators and nutrients on fruit retention, yield and quality of Acid lime (*Citrus aurantifolia* Swingle)
Full name of student	:	Yamini Sapaha
Major subject	:	Fruit Science
Name and address of the Major advisor	:	Dr. Vijay Kumar Professor and Head of Department Fruit Science, College of Agriculture IGKV, Raipur (Chhattishgarh)
Degree to be awarded	:	M.Sc. (Horticulture, Fruit Science)

Signature of the student

Signature of Major advisor

Date : 23/10/2020

Signature of Head of the Department

ABSTRACT

A field study was carried out on the effects of foliar application of growth regulators and nutrients on fruit retention, yield and quality of acid lime (*Citrus aurantifolia* Swingle) on seven years old acid lime trees cv. Phule Sharbati with thirteen treatments involving combinations of jasmonic acid (JA) at 1, 2 and 3 ppm, brassinosteroids (BR) at 5, 10 and 15 ppm, GA_3 and 2,4 -D each at 15 ppm and urea, KNO_3 and KH_2PO_4 each at 1% along with untreated control in a randomized block design subjected to three replications sprayed at three consecutive months at monthly interval after anthesis in *Ambia bahar* (spring flowering crop). Results indicated that jasmonic acid at 3 ppm showed significantly better performance in fruit set (20.98 %), fruits per plants (1234), yield (62.02 kg/plant), fruit breadth (31.36 mm), fruit juice contents (46.16 %), fruit volume (52.65 cc) and titratable acidity (7.50 %) significantly over untreated control. The treatment GA_3 15 ppm + urea 1% showed notable influence on fruit length (35.20 mm), maximum number of seeds fruits^{-1} (11.15) and biochemical parameters viz. TSS (7.70 %), ascorbic acid (30.10 mg/100 g), total sugars (1.23 %) and reducing sugars (0.72 %). The combined application of 2,4-D 15 ppm+ KNO_3 1% recorded maximum fruit retention (62.12 %), minimum fruit drop (37.88 %). The graded yield was influenced by growth regulators alone and with nutrients viz., jasmonic acid 3ppm, 2,4-D 15 ppm+ urea 1% and brassinosteroids 5 ppm having maximum percentage of fruit weight grade A (37.12 %), B (48.46 %) and C (48.27 %) respectively. However, three spray applications of BR 15 ppm at petal fall, fruit development and fruit maturation stages notably increased the fruit weight (52.36 g) over control (36.97 g). Overall results suggested that plant regulators in combination with nutrients could be a promising tool to increase qualitative and quantitative variables in acid lime.

शोध सारांश

अ.	शोधकार्य का शीर्षक	:	नीबू (*सिट्रस ऑरेंटीफ़ोलिया* स्विंगल) कि फल धारण, उपज एवं गुणवत्ता पर पादप होर्मोन एवं पोषक तत्व के प्रभाव का अध्य्यन ।
ब.	छात्रा का नाम	:	यामिनी सपहा
स.	प्रमुख विषय	:	फल विज्ञान
द.	प्रमुख सलाहकार का नाम और पता	:	डॉ. विजय कुमार (विभागाध्यक्ष) फल विज्ञान विभाग, कृषि महाविद्यालय, रायपुर (छत्तीसगढ़)
इ.	प्रदान की जाने वाली उपाधि	:	एम.एस.सी (उद्यानिकी) फल विज्ञान

Ysepaha
छात्रा का हस्ताक्षर

Vkumar
प्रमुख सलाहकार का हस्ताक्षर

Vkumar
विभागाध्यक्ष के हस्ताक्षर

दिनांक 23/10/2020

शोध सारांश

नीबू (*सिट्रस ऑरेंटीफ़ोलिया* स्विंगल) किस्म फूले शरबती के सात वर्षीय पौधों की फल धारण क्षमता, ऊपज एवं गुणवत्ता पर पादप वृद्धि नियामक एवं पोषक तत्वों का नीबू के पौधों पर छिड़काव का अध्ययन भा.कृ.अनुप-केंद्रीय नीबूवर्गीय

फल अनुसंधान संस्थान में किया गया | इस अध्ययन के लिए *रैंडमाइज्ड ब्लॉक डिज़ाइन* में ३ प्रतिकृति के साथ, १३ उपचारों का प्रयोग किया गया | ऊपचारों में क्रमश: *जैस्मोनिक एसिड (जेए)* १, २ और ३ पीपीएम, *ब्रसीनोस्टीरोइड्स* (बीआर) ५, १० और १५ पीपीएम, *जिब्रेलिक एसिड* एवं *२,४-डी* का समावेश १५ पीपीएम एवं *यूरिया पोटेशियम नाइट्रेट* और *मोनोपोटॅशियम फोस्फेट* १% सांद्रता और तुलना के लिए के साथ बिनाउपचारित पौधे थे | अम्बिया बहार में संलग्न ३ महीनों में एक माह के अंतराल पर फूलों के आने के बाद ३ छिड़काव किये गए | इन छिड़कावों के परिणाम निम्नानुसार पाये गए उपचार *जैस्मोनिक एसिड (जेए)* ३ पीपीएम में फल धारण २०.९८%, औसतन फलों की संख्या १२३४/पौधा, फुल उत्पादक   ६२.०२ किलो ग्राम प्रति पौधा, फल की चौड़ाई ३१.३६ मि.मी., फलों में रस की मात्रा ४६.१६%, ५२.६५ सी.सी. एवं *टाइट्रेटेबल* अम्लता ७.५०% इन सभी मापदंडो पर *जैस्मोनिक एसिड (जेए)* ३ पीपीएम के पौधे अनुपचारित पोधों की अपेक्षा बेहतर पाए गए | *जिब्रेलिक* अम्ल १५ पीपीएम + *यूरिया* १% के छिड़काव पर निम्न प्रकार के परिणाम पाए गए | औसतन फलों की लंबाई ३५.२० मि.मी., प्रति फल बीजों की संख्या ११.१५ एवं जैव रासायनिक मापदंड़ में कुल घुलनशील ठोस (मिठास) ७.७१%, *एस्कॉर्बिक* अम्ल ३०.१० मि.ग्राम/१०० ग्राम, कुल शर्करा १.२३% एवं नॉन-रिड्युसिंग शर्करा ०.७२% इस प्रकार अनुपचारित पोधों की अपेक्षा परिणाम बेहतर पाए गए | २,४-डी १५ पीपीएम + *पोटैशियम नाइट्रेट* १% के छिड़काव पर निम्न परिणाम पाए गए | अधिक फल धारण क्षमता ६२.१२% एवं न्यूनतम फल झड़न क्षमता ३७.८८% इस तरह अनुपचारित पौधों की अपेक्षा अच्छे परिणाम पाए गए |पादप वृद्धि नियामको एवं पोषक तत्वों में जैसें कि *जैस्मोनिक एसिड* (जेए) ३ पीपीएम, २,४-डी १५ पीपी एम और *ब्रसीनोस्टीरोइड्स* ५ पीपीएम में निम्नानुसार ऐ ३७.१२%, बी ४८.४६% और सी. ४८.२७% श्रेणियों के अनुसार फलों का उत्पादन प्राप्त हुआ | इस प्रकार,

ब्रसीनोस्टीरोइड्स के १५ पीपीएम छिड़काव पंखुडियों के विगलन, फलों के विकास एवं फलों के पकने की अवधि ३ लगातार एक माह के अंतराल पर छिड़काव करने पर अधिकतम फलों का भार ५२.३६ ग्रा., नियंत्रण ३६.९७ ग्रा. की अपेक्षा *ब्रसीनोस्टीरोइड्स* १५ पीपीएम बिनापचारित उपचारों की अपेक्षा इस उपचारित में अच्छे परिणाम पाए गए | इस प्रकार सभी परिणामों को देखते हुए यह सुझाव मिला है कि, पादप हार्मोन एवं पोषक तत्वों के संयोजन का नीबू पर गुणवत्ता और उत्पादन पर अच्छे परिणाम प्राप्त हुए हैं |

CHAPTER-1

INTRODUCTION

Citrus fruits are one of the most important fruits grown commercially in more than 50 countries of the world. Although sub-tropical in nature, they possess a greater adaptability to different climatic conditions and are grown in tropical and subtropical regions. In India, common citrus fruits grown are mandarins, sweet oranges, limes and lemons comprising 45, 25, 15 and 10 % area respectively. From ancient times, citrus fruit has been recognized as a natural source of providing nutrients and medicinal value. The total area of citrus crop in the world is 9.37 million hectares and the total production 129.17 million tonnes. The area of acid lime and lemon is 1.26 million hectares and production 13.51 million tonnes and total area of sweet oranges is 4.46 million hectare and production 75.41 million tonnes (FAO, 2018).

Acid lime occupies about 259.17 thousand hectares (28.87%) of the total area under citrus in India is 897.75 thousand hectares and total production of 11040.22 thousand MT and productivity of 12.29 t/ha (NHB, 2018-19) in the country. The area under acid lime cultivation in Maharashtra alone is 29.16 thousand hectares, with a production of 263.01 thousand MT and productivity of 9.01 t/ha (NHB, 2018-19). The total area under citrus fruit in Chhattisgarh is 13.78 thousand hectares with a total production of 110.67 thousand MT with a productivity of 8.03 t/ha. the total area under limes and lemons 12.64 thousand hectares and production of 104.16 thousand MT (NHB, 2018-19).

The citrus fruits are well known for their refreshing fragrance, thirst-quenching ability, and a good source of vitamin C. In addition to their value-added products such as pickles, juice, squash and cordials which are widely used in India, the by-products like lime peel oil, peel powder are also very popular in the soap and cosmetics industries. The 100 grams of fruit juice contains 80 per cent of water, 26 IU vitamin A (carotene), 20 mg vitamin B1, 0.1 mg riboflavin, 63 mg vitamin C, 1.83 mg iron (Fe), 0.16 mg copper (Cu), 0.30% oxalo-acetic acid, 8.2% malic acid and alkaline salt therefore they are very essential for human health (Rangel, 2010).

Acid lime (*Citrus aurantifolia* Swingle) belongs to the family Rutaceae. It originated in India and has a chromosome number of 2n=18. Plant is medium in size and vigorous in nature, spreading branch habit and bushy with numerous, slender, fine willowy stemmed branch-lets densely armored with small, slender spines. The leaves are dense and are small, pale green, broadly lanceolate, blunt spotted leaves with definitely winged petioles. Flower buds and flowers are small and bloom year-round, but mainly in spring and late summer. Fruits are quite small, round obovate or short-elliptical, base usually rounded, greenish yellow in color and thin skinned, core solid at maturity fresh greenish color and juice highly acidic. Seeds are small smooth, white color of cotyledon and highly polyembroynic in nature.

The flowering occurs in three distinct flushes under central and southern India conditions known as "*bahar*" (bloom) viz., *ambia* (the crop, flowering of which coincides with the flowering of mango fruit i.e. *Amba* in Marathi hence the name *Ambia bahar*), *mrig* (the crop, flowering of which coincides with occurrence of *Mrig* constellation marking the onset of rainy season) and *hasta bahar* (the crop, flowering of which coincides with occurrence of *Hasta* constellation).

The plant hormones (or phytohormones) are the naturally producing organic substances in the plant that are produced in minute quantities and regulates the growth and other physiological functions of a plant. The plant growth regulators, also called as biostimulators or bio inhibitors act inside the plant cell. They either stimulate or inhibit the enzymes and enzymatic system and thus regulate plant metabolism. Hence, such chemical substances have proven to be an important component of modern fruit production technology both for improving the quantity as well as quality of fruit crops (Jain and Dashora, 2011). It alters the parameters like vegetative growth, fruit set, fruit drop, yield attributing parameters (Hota *et al.*, 2017a; Priyadarshi *et al.*, 2017). Many synthetic substances mimicking properties of plant hormones such as auxins, giberellins, cytokinins, abscisic acid, ethylene, brassinosteroides and jasmonic acid, CCC and maleic hydrazide are being used as plant growth regulators for specific purposes in crop production.

Gibberellins (GAs) are tetracyclic diterpenoid compounds involved in development of seed germination, cell division and elongation, induction and development of flowers and growth of fruit (Fuentes *et al.,* 2019).

2,4-dichlorophenoxyacetic acid (2,4-D) works as a growth regulator in less than 20 ppm of various fruit crops.

Brassinosteroids (BRs) have been identified in many plant species since the discovery of brassinolide (Grove *et al.*, 1979), apoly-hydroxy-steroidal lactone, isolated initially from *Brassica napus* pollen (Bajguzand Tretyn, 2003; Zullo and Kohout, 2004). Brassnosteroids are polyhydroxy steroid phytohormones that play critical roles in the cell division, elongation, vascular differentiation, flowering, pollen growth and photo-morphogenesis. Brassinosteroids have also been reported to be involved in development and ripening of fruits (Fuentes *et al.,* 2019).

The methyl ester jasmonic acid was first isolated from *jasminum grandiflorum* essential oil (Demole *et al.,* 1962). The senescence promoter effect was one of the biological activities observed for jasmonate (Wasternack, 2006). Jasmonic acid is bioactive isoleucine conjugate (JA-Ile) which is one of the most important signals for the response of biotic stress and abiotic stress in plants and is active in root growth, seed germination or senescence.

Many time acid lime tends to bear heavily under ideal growth conditions compromising fruit size and quality. It is imperative to attempt achieving a uniform size and quality crop of acid lime with cultural amendments in order to fetch remunerative prices to the producer in the markets. Scanty literature is available on use of growth regulators and fruit sizing foliar use of nutrients at critical growth stages of acid lime crops. Therefore, the present investigation entitled **"**Effect of foliar application of growth regulators and nutrients on fruit retention, yield and quality of acid lime (*Citrus aurantifolia* Swingle**)"** was undertaken at ICAR-Central Citrus Research Institute (CCRI), Nagpur (MH).

Objectives:

1. To standardize the concentrations of growth regulators and nutrients for optimum fruit retention and yield in acid lime
2. To observe the effects of growth regulators and nutrients on fruit size and quality in acid lime.

CHAPTER-II

REVIEW OF LITERATURE

The plant growth regulation substances are systematically produced organic chemical substances, where in extremely minute quantities influence the development process. In the past few years, intensified research has been carried out towards the practical use of plant growth regulators and nutrients to improve the vegetative growth, flowering, fruit set, fruit retention, yield and quality of fruits.

The related literature about present investigation on "Effect of foliar application of growth regulators and nutrients on fruit retention, yield and quality of acid lime (*Citrus aurantifolia* Swingle)" has been reviewed in this chapter.

2.1. Effect of growth regulators and nutrients in morphological parameters:

2.1.1. Plant growth parameters

Modesto *et al*. (1996) reported that the Rangpur lime seedlings were sprayed with GA_3 at 0, 25, 50, 100 or 150 ppm at 14-day intervals, from the 70^{th} to the 210^{th} day. He found that GA; applications significantly increased plant height (at 150 ppm) and stem diameter (25 and 50 ppm).

Kalalbandi *et al.* (2003) reported that GA_3 50 ppm enhanced number of leaves. The circumference and branches number were improved in NAA at 50 ppm treatments in Acid lime.

Singh *et al.* (2008) observed the maximum plant growth viz., height of plant, canopy spread and stem girth by application of 25 ppm GA_3 in aonla.

Shinde *et al.* (2008) conducted an experiment with seven treatments, viz., 2, 4- D (10 and 20 ppm), 2, 4, 5-T (20 and 30 ppm) GA_3, (25 and 50 ppm) and control (no spray). All treatments of plant growth regulators were significantly superior over control (no spray). They found that GA_3-50 ppm is more useful for improving plant growth, yield and quality of acid lime followed by GA_3 25 ppm, 2, 4-D 20 ppm and 2, 4,5-T 30 ppm.

Debaje *et al.* (2010) studied that the effect of foliar sprays of growth regulators viz. GA_3 and NAA and nutrients like urea and KNO_3 singly or in combination on growth and yield of *Hasta bahar* acid lime. The results revealed that two foliar sprays of 2 per cent urea and GA_3 (100 ppm) produced maximum vegetative growth, fruit size and fruit yield per tree. Same treatment also improved the fruit weight, volume and quality (juice per cent, TSS and ascorbic acid content) and reduced the peel thickness and acidity (Debaje *et al.* 2011).

Ahmed *et al.* (2012) recorded that the application of plant growth regulators (20 ppm 2,4-D, GA_3 30 ppm and BA 10 ppm) significantly influenced the vegetative characters of Washington navel orange viz., height, canopy spread and stem girth.

2.2. Effect of growth regulators and nutrients on fruit retention and yield

Kadam and Warke (1980) reported that a high yield of fruits in mandarin was observed with GA_3 100 ppm.

Prasad and Singh (1980) reported that foliar application of gibberellin at 150 ppm on ten-year-old acid lime trees resulted in a better fruit set.

Singh and Lal (1980**)** reported that a higher number of fruits were retained in litchi when the trees have been treated with gibberellic acid 40 ppm.

Jose Eduardo and Friedrick (1984) found that the application of GA_3 at 200 ppm along with 10 ppm 2, 4-D at five weeks after mid-bloom increased the number of fruits in Navel orange in Florida.

Singh and Phogat (1984) recorded that the foliar application of GA_3 40 ppm increased the fruit retention in litchi.

Singh *et al.* (1987) reported that spraying of GA_3 50 ppm gave the highest fruit yield in ber.

Oosthuyse (1996) obtained increased fruit set through spraying of two to four percent KNO_3 at flowering in mango.

Rabe and Van Rensberg (1996) observed that the foliar spraying of GA_3 20 ppm at full bloom and four percent KNO_3 at six weeks after full bloom increased the yield in 'Ellendale' tangor.

Chanta and Misra (1998) reported that the application of GA_3 at 50 ppm caused the lowest number of seeds per fruit in guava.

Munish Narula *et al.* (1999) reported that the application of GA_3 successfully decreased the number of seeds per fruit of Kinnow mandarin.

Rubi Rani and Brahamachari (2000) reported that spraying of GA_3 20 ppm caused an enhancement in fruit weight and volume in mango cv. Amrapali.

Tripati (2002) reported the spraying of KNO_3 one percent in 'Dashehari' mango increased the yield significantly over control.

Suresh Kumar *et al.* (2003) reported that the application of KNO_3 one percent resulted in a higher yield (28.11 kg) in Mango.

Prasana Kumar and Reddy (2004) observed that fruit yield was higher in trees sprayed with thiourea at three percent in ber.

Thirugnanavel *et al.* (2007) studied the effect of plant growth regulators viz, GA_3 and cycocel, chemicals viz, KNO_3, thiourea and salicylic acid on flowering and fruiting in acid lime. The result revealed that the application of GA_3 50 ppm in June + cycocel 1000 ppm in September + KNO_3 2 % in October significantly enhanced number of flower shoots, fruit set, fruit retention, no of fruits and yield.

Modise *et al*. (2009) evaluated the effect of 2,4-dichlorophenoxyacetic acid (2,4-D) on reducing the premature fruit drop. Different concentration levels of the 2,4-D @ 8, 16 and 20 mg/L were applied exogenously to mature fruit trees of sweet orange (*Citrus sinensis* L). The results indicated that, 2,4-D 16 and 20 mg/L were effective in controlling the fruit drop by enhanced fruit retention, as well as improving the quality of navel oranges under dry climatic conditions.

Nawaz *et al*. (2011) evaluated the ability of plant growth regulators on fruit set percentage, yield and quality of Kinnow mandarin. Various concentrations of 2,4-

D (10, 20 and 30 mg/L) and NAA (5, 10 and 20 mg/L) were applied at bloom stage. The results indicated that 10 mg/L 2,4-D was significantly increased the fruit set percentage, fruits plant^{-1}, weight, juice content, TSS and ascorbic acid in Kinnow mandarin.

Neha Patel and Pandey (2012) studied that the effect of foliar application of urea (1, 2 and 3 percent), NAA (10, 20 and 30 ppm), GA_3 (25,50 and 100 ppm) and 2,4-D (10, 15 and 20 ppm) sprayed at full bloom and pea stage of Acid lime. The result indicated that the growth regulators significantly increased the fruit retention at various stages of fruit growth and development over unsprayed. The maximum (62.59%) fruit retention was observed in the application of NAA 20 ppm at harvest followed by urea 2 percent (52.10 %). Among various treatments, minimum fruit drop was noted in 20 ppm NAA followed by Urea 2 percent in all three waves of fruit drop.

Abubakar *et al.* (2013) studied the effect of different concentrations of bio stimulants. The results revealed that the significantly highest fruit set and minimum flower drop was recorded with the application of Vipul + Homobrassinolides (1.5 + 5 ml/L) in Pomegranate.

Jagtap *et al.* (2013) studied the effect of foliar application of plant growth regulators and micronutrients on yield and quality of acid lime (*Citrus aurantifolia* Swingle). The results indicated that GA_3 50 mg/L significantly increased the yield attributing characters like fruit volume (47.90 cm^3), fruit diameter (4.54 cm), fruit weight (47.40 g) and fruit yield per tree (46.38 kg). In case of number of fruits per tree, the treatment NAA 200 mg/L significantly increased the number of fruits per tree (1020.33). Biochemical characters like TSS (9.58 ^{0}Brix) and ascorbic acid content (30.41 mg/100g pulp) were significantly increased, while number of seeds per fruit (6.13) and acidity (7.05 %) were reduced in case of GA_3 50 mg/L.

Lakshmi *et al.* (2014) evaluated the effect of GA_3, CCC and KNO_3, and their various combinations on fruit yield and quality of acid lime. They found that treatments promoted the yield and quality parameters. The results revealed that the foliar spray of GA_3 50 ppm in June followed by cycocel 1000 ppm in September and KNO_3 1% in October was found superior with respect to number of fruits per tree

(529.34), fruit weight (41.12 g), yield (24.08 kg/tree) and quality (juice content 34.34 ml and TSS 6.92 ^{0}Brix).

Omima *et al.* (2014) reported that the effect of growth regulators like ascorbic acid, proline and jasmonic acid on olive. The jasmonic acid at 15 ppm and 25 ppm on olive tree significantly increased the fruit set, yield and quality traits.

Boray *et al*. (2015) studied the effects of two natural biostimulants *i.e.*, Milagrow (brassinolide *a.i.* at 10, 15 and 20 ppm) and yeast extract at 1000, 1500 and 2000 ppm increase fruit set, yield and decreased fruit drop of Washington Navel orange trees.

Debbarma and Hazarika (2016) studied the different concentrations of PGRs with combinations. The treatment GA_3 100 ppm + cycocel 1000 ppm + KNO_3 1 % significantly enhanced the number of flowers/shoot, number of fruits /tree and average fruit yield of the crop in Acid lime.

Deshmukh *et al*. (2015) studied the effect of plant growth regulators and micronutrients with combinations sprayed before the flower emergence on acid lime. The minimum days taken to emergence of flower bud (39.57), duration of flowering (24.07), days to 50% fruit set (6.54) and days taken to fruit maturity (145.90) were observed with application of GA_3 50ppm + Paclobutrazol 3.5g *a.i.*/tree (soil application) + KNO_3 0.2% + Zn 0.3% + Boron 0.1% (T_5), whereas fruit drop (5.92%) was minimum with GA_3 50ppm + cycocel 2000ppm + KNO_3 0.2% + Zn 0.3% + Boron 0.1% (T_3). Treatment T_3 also increased the number of flowers per meter shoot length (49.65) and fruit yield (8.90).

Eid *et al.* (2016**)** evaluate the effect of milagrow (extracted from pollen grains of rapeseed (*Brassica napus*) as a source of brassinolide phytohormone), nutrient compounds (potassium 10 %, phosphorus 20 %, boron 3 % and brassinolide 0.2 %), on fruit set and fruit retention (%), number of fruit/tree, yield, and fruit quality of avocado tree cv. Fuerte in various growth stages; a) swollen bud stage, b) Full bloom and c) beginning of fruit set. The results indicated that 7.5 g/100 L milagrow sprayed at swollen bud stage increased fruit set, fruit retention, yield and quality in avocado cv. Fuerte.

Thapliyal *et al.* (2016) evaluated that the effect of plant growth regulators viz., GA_3, BR (brasssinosteroid), GA_3 + BR and water as control on pear (*Pyrus pyrifolia* (Burm.) Nakai). The spray of GA_3 @ 50 ppm improved the length of fruit (6.98 cm), fruit breadth (6.81 cm), fruit weight (175.9 g) and fruit volume (171.16 cc). The increased fruit quality was observed either singly or in the combined application of GA_3 and BR.

Hidayatullah Mir and Itoo (2017) observed the effects of 2,4-D and the frequency of application on pre harvest fruit drop and quality of Kinnow mandarin (*Citrus reticulata*, Blanco) at 10 and 20 ppm in monthly intervals during September, October and November. Exogenous application of 20 ppm 2,4-D significantly decreased pre-harvest fruit drop percentage leading to increase in total number of fruits per plant, fruit weight, juice percentage, total soluble solids, acidity, vitamin C, reducing sugars and non -reducing sugars.

Ranganna *et al*. (2017) observed that the effects of growth regulators on fruit parameters in acid lime (*Citrus aurantifolia,* Swingle) cv. Balaji. The results indicated that the higher length of fruit, diameter of fruit, volume of fruit and weight of fruit were recorded with foliar application of GA_3 @ 50 ppm + CCC @ 1000 ppm + KNO_3 2 %.

Chouhan *et al*. (2018) conducted the study on effect of plant growth regulators and nutrients viz., Urea, Boron and 2,4-D with their different combinations in Acid lime. The results revealed that the foliar application of Urea 2% + Boron 0.6% + 2,4-D 20 ppm significantly increased the physical parameters of fruit *i.e.* fruit length, fruit diameter, fruit volume, fruit weight, juice content and moisture content of peel, and bio- chemical parameters *i.e.* TSS, TSS: Acid ratio and ascorbic acid when over control.

Tagad *et al.* (2018) studied the effects of GA_3, $ZnSO_4$ and $FeSO_4$ on acid lime. Among the treatments, GA_3 (50 ppm) + $ZnSO_4$ (1%) + $FeSO_4$ (1%) obtained higher plant height, plant spread (east-west and north-south), the maximum number of fruits tree^{-1} (148.00 fruits tree^{-1}), fruit weight (43.33 g), fruit volume (41.30 cm^3), yield (6.41 kg tree^{-1}), fruit set (51.20 %), number of flower/shoot (18.57) and the minimum fruit drop (35.20 %).

Rana and Reddy (2018) evaluated that the effect of spraying of GA_3 30 ppm was more effective in increasing the fruit weight, fruit size and length compared to control in Sweet orange.

Ali and Zayat (2019) studied the effect of salicylic acid (200 and 400 mg/L), Jasmine oil (2 and 4 ml/L), radish root extract (50 and 100 ml/L) and Kaolin particles film (5000 and 10000 mg/L) on vegetative growth, leaf area index, leaf chlorophyll value, fruit set, fruit retention, yield and fruit quality parameters (fruit weight, fruit diameter, secondary fruit diameter, peel thickness, firmness, juice content, of Washington Navel Orange. The results revealed that 4ml/L of jasmine oil is more effective on improving the fruit set, fruit retention, no. of fruits/plant, fruit weight and yield per plant of Washington navel orange.

Bharti *et al.* (2019) observed that the spraying of growth regulators viz., 2, 4-D (10 and 20 ppm), GA_3 (25 and 50 ppm) and NAA (10 and 20 ppm) on fruits per plant, weight, length, breadth and juice content of Kinnow mandarin. The results reported that the exogenous application of 2, 4-D (20 ppm) significantly decreased the pre-harvest fruit drop percentage leading to an increase in the total number of fruits per plant, fruit weight, length, fruit breadth and juice contents.

Deshlehra *et al.* (2019) reported that the treatment GA_3 100 ppm + KNO_3 2% + Salicylic acid 200 ppm + FeSo4 1% + Boron 1% significantly increased the fruit setting percentage (87.1 %), fruit retention percentage (84.5 %), total soluble solids (8.93 ^{0}Brix), acidity (6.62 %), ascorbic acid (29.9 mg) and decreased the fruit drop percentage (15.5 %) in Acid lime.

Maria E-Garcia-Pastor *et al.* (2019) studied the effects of methyl jasmonate applied at different concentrations (1, 5 and 10 mmol L^{-1}) on pomegranate. The results revealed that the spraying of methyl jasmonate significantly increased the yield at concentrations of 1 and 5 mmol L^{-1}.

Shuchi Parauha and SK Pandey (2019) studied the effects of spraying of plant growth regulators and nutrients on mango (*Mangifera indica* L.) cv. Amrapali. Spraying of combination of nutrients viz., KNO_3 (2%), urea (2%), $ZnSO_4$ (0.8%) and $FeSO_4$ (0.4%), and growth regulators viz., NAA (50 & 25 ppm) and GA_3 (30 & 20 ppm). The results showed that the GA_3 30 ppm + KNO_3 2% increased the number of fruits at the initial stage, more fruit retention percentage at harvest stage, fruit yield, fruit weight, fruit length, fruit width, fruit volume and peel weight, and also improved the biochemical parameters like TSS, acidity, reducing and non-reducing sugar.

2.3 Effect of growth regulators and nutrients on quality traits.

Kumar *et al.* (1975) reported that the ascorbic acid content and TSS could be improved by foliar application of GA_3 50 ppm at full bloom stage in sweet lime.

Chapman *et al.* (1979) reported that GA_3 at 20 ppm reduced the acidity in mandarin.

Babu *et al.* (1982) observed that a slight increase in ascorbic acid content in Kagzi lime with sprayed of GA_3 30 ppm.

Daulta and Beniwal (1983) observed that the maximum fruit weight was obtained in sweet orange when the trees were sprayed with gibberellic acid at 750 ppm.

Ratna Babu *et al.* (1984) reported that the gibberellic acid at 10 to 40 ppm could not increase the acidity in Pant lemon.

Singh *et al.* (1990) observed that the foliar application of GA_3 50 ppm increased the ascorbic acid content in guava.

Singh and Rajput (1991) reported that the foliar application of GA_3 30 ppm increased the total sugars and reducing sugars in the fruit of mango cv. Langra.

Singh and Rajput (1991) reported that increase in the fruit weight of mango cv. Langra was due to gibberellic acid (30 ppm) treatment.

Erner *et al.* (1993**)** reported that the TSS were increased in ‘Shamouti’ and ‘Valencia’ oranges when the trees sprayed with 20 ppm 2,4-D and five percent KNO_3.

Kumar and Singh (1993) reported that spraying of GA_3 100 ppm increased the ascorbic acid content in mango.

Dhillon *et al.* (1999) reported that the juice content was not increased significantly with spray of gibberellic acid in Kinnow mandarin

Kumar and Singh (1993) reported that spraying of GA_3 100 ppm increased the ascorbic acid content in mango.

Watanabe *et al*. (1997) evaluated that the brassinosteroid compound (TS303) on fruit setting, growth and preventing from low-temperature injury on Japanese persimmon and grapevine. The TS303 application of 0.01 ppm was significantly improved the fruit set (76.2%) and fruit weight (116.2) in persimmon. In grapevine, it enhanced the number of berries, bunch weight and TSS.

Nath and Barauh (2000) reported that double spray of GA_3 100 ppm recorded the maximum total sugar of 2.46 percent in Assam lemon.

Nirmaljit Kaur *et al.* (2000) recorded that the foliar application of GA_3 20 ppm increased the total soluble solids significantly over control in Kinnow mandarin.

Dubey (2002) observed that in Khasi mandarin highest total soluble solids were observed by spraying of GA_3 90 mg L^{-1}.

Tripati (2002) reported that spraying of one percent KNO_3 increased the total soluble solids in mango cv. Dashehari.

Gomes *et al.* (2006) carried out an experiment to observe the effect of brassinosteroid analogue (0.1 mg of brassinosteroid analogue BB-16) on yellow passionfruit (*Passiflora edulis* f. flavicarpa) on different stages. The results indicated that brassinosteroid sprayed during the period of reproductive development increased the number of fruits plant^{-1} and soluble solids when compared to control.

Kachave and Bhosale (2009) evaluated application of growth regulators like NAA (100 ppm and 200 ppm) and GA_3 (50 ppm) singly or in combination with micronutrients (0.5 % and 1% spray) at flowering and pea-size fruit stage on fruit quality. The results indicated that the NAA 200 ppm + micronutrient mixture 1 % recorded the maximum total soluble solids, acidity, ascorbic acid, reducing sugar of fruits in Kagzi lime.

Debaje *et al.* (2010) carried out the study on the effects of foliar sprays of plant growth regulators viz., GA_3, NAA, and nutrients like urea, KNO_3 singly and in the combinations. The results indicated that foliar spray of KNO_3 2% and GA_3 100 ppm increased fruit weight, fruit volume, juice percentage, TSS and ascorbic acid of acid lime.

Nawaz *et al*. (2011) evaluated the ability of plant growth regulators on fruit set percentage, yield and quality of Kinnow mandarin. Various concentrations of 2,4-D (10, 20 and 30 mg/L) and NAA (5, 10 and 20 mg/L), were applied at the blooming stage. The results indicated that 10 mg/L of 2,4-D significantly increased the fruit set percentage, fruits/plant, fruit weight, juice content, TSS and ascorbic acid of Kinnow mandarin.

Martinaze-Espla *et al*. (2014) studied the effect of methyl jasmonate at three concentrations (0.5, 1.0 and 2.0 mM) on two plum cultivars viz., Black Splendor and Royal Rose for fruit development. The results indicated that the fruit size and fruit weight were increased by the application of methyl jasmonate in Black Splendor (0.5 mM) and Royal Rose (2.0 mM) cultivars of plum.

Roghabadi and Pakkish (2014) studied the effects of brassinosteroid (BR) on yield, fruit quality and storage of 'TakDanehe Mashhad' sweet cherry (*Prunus avium* L.). The brassinosteroid applied at four different stages of plant viz., a) swollen bud stage, b) beginning of fruit set, c) swollen bud stage + beginning of fruit set, d) beginning of fruit set + 10 days of pre-harvest. The results revealed that the application of brassinosteroid to 'TakDanehe Mashhad' sweet cherry improved the fruit color by increasing fruit anthocyanin content, organic acids, ascorbic acid and phenol content when sprayed at swollen bud stage. Further it also improved the yield and quality.

Boray *et al*. (2015) studied the effects of two natural biostimulants *i.e.* Milagrow (brassinolide *a.i.* at 10, 15 and 20 ppm) and yeast extract at 1000, 1500 and 2000 ppm on Washington navel orange trees. The results revealed that the foliar application of Milagrow at 15 and 20 ppm were found superior over control.

Batta *et al.* (2016) reported that the effect of foliar application of bio-regulators and nutrients on the quality of lemon (*Citrus limon* Burma.) cv. Pant

Lemon-1. Based on the overall performance of treatments on quality characters of fruits, it can be concluded that the values for fruit set, days to maturity, fruits per plant, fruit length, fruit juice content, total soluble solids, total sugars, shelf-life of fruits had been improved in the application of GA_3 15 ppm, GA_3 20 ppm and 1% urea. The maximum fruit weight, fruit volume and acidity were recorded with NAA (50 ppm). However, the maximum vitamin C was recorded under NAA (10 ppm), 0.5% and 1% urea foliar application.

Kaur *et al*. (2016) observed the effect of KNO_3 and 2,4-D in combination (2.5+20µg/ml) to minimize the fruit drop and to improve the fruit quality of Kinnow mandarin. They observed that KNO_3 and 2,4-D in combination (2.5+20µg/ml) was found more effective in improving the fruit weight (232g/fruit), size (6.51x7.44cm), TSS:Acid ratio (15.0), Vitamin C (50.46 mg/100 ml juice) and juice percent (54.66). Thus, the synergistic effect of KNO_3+2,4-D (2.5% and 20µg/ml) improves fruit yield and quality in Kinnow mandarin by reducing the fruit drop.

Thapliyal *et al.* (2016) recorded that the foliar feed of BR @ 1 ppm significantly enhanced TSS (12.91°Brix) and reduced the treatable acidity (0.42%), while the highest ascorbic acid content (6.95 mg/100 g) and non-reducing sugar (0.44%) was observed in the combined application of (GA_3 @ 100 ppm + BR @ 1 ppm). Total sugar (7.88%) and reducing sugar (7.45%) was increased in the combined application of (GA_3 @ 50 ppm + BR @ 0.5 ppm).

Itoo *et al.* (2017) observed the effects of 2,4-D and the frequency of application on initial fruit drop and quality of Kinnow mandarin (*Citrus reticulata* Blanco) at 10 and 20 ppm concentrations sprayed at monthly intervals during September, October and November. Exogenous application of 2,4-D at 20 ppm significantly decreased the initial fruit drop percentage leading to an increment in the total no. of fruits per plant, fruit weight, fruit juice percentage, TSS, acidity, vitamin C, reducing sugars and non-reducing sugars.

Ali and Zayat (2019) studied the effect of salicylic acid (200 and 400 mg/L), Jasmine oil (2 and 4 ml/L), radish root extract (50 and 100 ml/L) and Kaolin particles film (5000 and 10000 mg/L) on TSS, TA, TSS/TA ratio, ascorbic acid of Washington navel orange. The results revealed that 4ml/L of jasmine oil was more effective on improving the TSS, TA, TSS/TA ratio, ascorbic acid of Washington navel orange.

Shuchi Parauha and SK Pandey (2019) evaluated the effects of foliar application of growth regulators and nutrients on mango (*Mangifera indica* L.) cv. Amrapali. Spraying of combination of nutrients viz., KNO_3 (2%), urea (2%), $ZnSO_4$ (0.8%) and $FeSO_4$ (0.4%), and growth regulators viz., NAA (50 & 25 ppm) and GA_3 (30 & 20 ppm). The obtained results showed that GA_3 30 ppm + KNO_3 2% improved the biochemical parameters like TSS, acidity, reducing and non-reducing sugar.

CHAPTER –III

MATERIALS AND METHODS

An experiment entitled "Effect of foliar application of growth regulators and nutrients on fruit retention, yield and quality of acid lime" was conducted at ICAR-Central Citrus Research Institute, Nagpur, Maharashtra during 2019-2020.

3.1 Experimental Materials

3.1.1. Experimental field

The experimental field was situated at the experimental farm of ICAR-Central Citrus Research Institute, Nagpur. The experimental field is situated between $21^{0}15'$ latitude and $79^{0}02'$ longitude. The site receives 1137.83 mm of rainfall annually. The mean maximum and minimum temperatures are 34.25 ^{0}C and 21.14^{0}C respectively.

3.1.2. Weather and climate

The temperature and relative humidity during the experimental period were recorded daily from the IMD website. The rainfall data were measured using rain gauge and presented in fig.1.

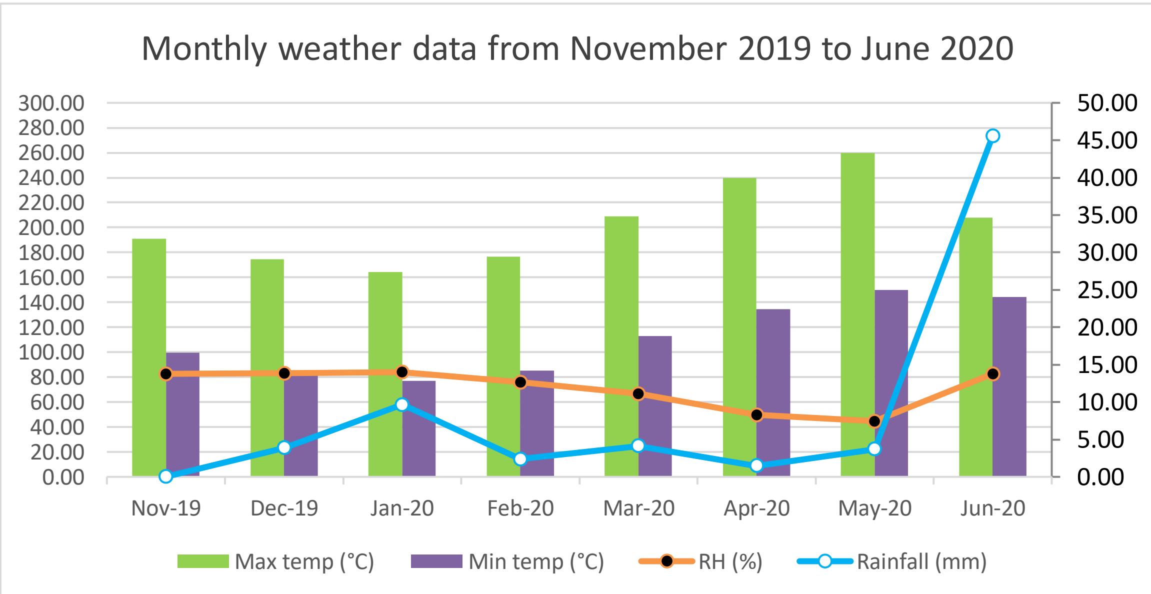

Fig. 3.1. Weather data from November 2019 to June 2020.

3.1.3. Soil characteristics

The soil type of experimental site was clay loam (42.5 % sand: 22.1 % silt: 35.3 % clay). The pH and EC of the soil were 7.2 and 0.154 dSm^{-1} respectively.

3.2 Experimental Methods

3.2.1. Experimental details

The present experiment was laid out in a randomized block design with three replications. The trial was carried out during *Ambia bahar* of 2019-20 on seven years old, 78 uniform-sized trees spaced at 6 x 6 m acid lime cv. Phule Sharbati. Initially, the shoots were slightly thinned to maintain uniform canopy. Two trees were used for each treatment per replication.

3.2.2 Treatments details:

The treatments consisted of combinations of chemicals and plant growth regulators and the details are furnished below table no. 3.1:

Treatment No.	**Treatments**
T_1	Jasmonic acid @ 1 ppm
T_2	Jasmonic acid @ 2 ppm
T_3	Jasmonic acid @ 3 ppm
T_4	Brassinosteroid @ 5 ppm
T_5	Brassinosteroid @ 10 ppm
T_6	Brassinosteroid@ 15 ppm
T_7	GA_3@15 ppm + Urea 1%
T_8	2,4 –D @15 ppm + Urea 1%
T_9	GA_3@15 ppm + KNO_3 1%
T_{10}	2,4 –D @15 ppm + KNO_3 1%
T_{11}	GA_3 @15 ppm + Monopotassium phosphate 1%
T_{12}	2,4 -D@ 15 ppm +Monopotassium phosphate 1%
T_{13}	Control

3.2.3. Schedule of spraying

The growth regulators and chemicals were sprayed three times. The first spray was done after petal fall stage in the second week of February. The second spray was carried out after 21 days of the first spray at button stage (fruit size 12-14 mm length and 4-6 mm diameter with pedicel) of fruit during the second week of March. The third or last spray was done after 21 days of the second spray in the first week of April (32-35 mm length and 20-22 mm diameter of fruit with pedicel). Every plant was sprayed thoroughly by taking care to wet the whole plants. It was fully ensured that all the sides of the plant were covered completely by the spray solution.

3.2.4. Fertilizer application

The recommended doses of fertilizers (N 800g: $P_2O_5$200g: K_2O 100g per plant) were applied as urea, diammonium phosphate (DAP) and muriate of potash (MOP). The fertilizers were applied by making the ring around the plant and covered it with soil, and irrigated after that. The full dose of FYM and half dose of NPK were applied before monsoon (May-June) and remaining half of NPK were applied during October-November. To carry out the experiment in *Ambia bahar*, chlormequat chloride (CCC) was sprayed @ 4 ml per litre of water in November.

3.2.5. Preparation of spray solution

Stock solutions of 1000 ppm GA_3 and 2-4 D were prepared by dissolving 1 g of respective chemicals in a small quantity of ethanol (approximately 20-25 ml) and the volume was made up to 1 litre by adding double distilled water to it. 250 ppm of jasmonic acid stock solution was prepared by dissolving 250 mg of jasmonic acid in a small quantity of ethanol and the final volume was made to one litre by adding double distilled water to it. The commercial-grade 0.15 % brassinosteroid was used. Nutrient solutions were prepared by dissolving a requisite amount of chemicals in the water.

3.3. Observations recorded

3.3.1. Morphological parameters

3.3.1.1. Plant height

The plant height was measured from ground level to the growing tip with the help of measuring scale before flowering and expressed in metre (m).

3.3.1.2. Canopy spread

Canopy spread was recorded in both east-west and north-south directions before flowering with the help of metre-scale and expressed in metre (m).

3.3.1.3. Stem girth

Stem girth was measured at 15 cm above from the ground height before the flowering stage with measuring tape and expressed in centimetres (cm).

3.3.2 Yield attributing parameters

3.3.2.1 Number of flowers/meter shoot length

The total number of flowers (staminate and hermaphrodite) produced per meter length was recorded in five randomly selected shoots from each tree. The mean value was expressed in numbers per meter shoot length.

3.3.2.2 Number of fruits per meter shoot length

The total number of fruits produced per meter length was recorded in five randomly selected shoots from each tree at the time of harvest. The mean value was expressed in numbers per meter shoot length.

3.3.2.3. Fruit set percentage

The number of flowers born on each labelled shoots and number of fruits set on the same shoot was counted and the fruit set percentage was calculated as follows and expressed in percentage.

$$\text{Fruit set (\%)} = \frac{\text{No. of initial fruits/shoot}}{\text{No. of flowers/shoot}} \times 100$$

3.3.2.4. Number of fruit set

The fruit set count of north-south and east-west directions was taken out by tagging four of shoots in each direction of the whole plant.

3.3.2.5 Fruit drop percentage

The fruit drop of observational plants was measured in percentage by using flowers per shoot, fruit set and final fruit retention on the plant. Naturally, fallen fruits were collected, counted and estimated as fruit drop in per cent.

3.3.2.6 Number of fruits per plant

The number of fruits harvested at each harvest was computed and the total was expressed as a number of fruits per tree.

3.3.2.7 Grade-wise yield

Grade-A

Out of the total fruits harvested from a tree, fruits weighing 50-55g and above were classified as “Grade-A” fruits and expressed in per cent proportion of total yield.

Grade-B

Out of the total fruits harvested from a tree, fruits weighing 40-50g were classified as “Grade-B” fruits and expressed in per cent proportion of total yield.

Grade-C

Out of the total fruits harvested from a tree, fruits weighing below 30-40g were classified as “Grade-C” fruits and expressed in per cent proportion of total yield.

3.3.2.8 Yield per plant

The yield of fruits harvested at each harvest was computed and the total was expressed in kg per tree.

3.3.2.9 Fruit yield

The total yield was calculated by multiplying the single tree yield and total number of plants per hectare and expressed as t ha^{-1}.

3.3.3 Physical parameters

Five mature fruits from all directions were randomly selected from each tree to record the physical parameters and the same fruits were used estimation of fruit quality characters.

3.3.3.1 Fruit length

The fruit length was recorded from stylar end to the blossom end of the fruit by using vernier calliper and the mean was calculated and expressed as millimetres (mm).

3.3.3.2 Fruit breadth

The fruit breadth was measured at the central portion of the fruit with the use of vernier calliper and the mean was calculated and expressed as millimetres (mm).

3.3.3.3. Fruit weight

The five selected fruits taken for recording the fruit size were weighing on an electronic balance and the average fruit weight was expressed in gram (g).

3.3.3.4. Juice content

The fruit juice was extracted by hand-operated squeezer and the juice percentage was measured from the juice weight and total weight of fruit and expressed as per cent (%).

3.3.3.5. Fruit volume

The fruit volume was measured by water displacement method and expressed as a cubic centimetre (cc).

3.3.3.6 Peel thickness

The peel thickness was measured using vernier calliper and expressed as millimetres (mm).

3.3.3.7 Number of seed per fruit

The seeds extracted from each fruit were counted and the mean was expressed in numbers per fruit.

3.3.3.8 Seed weight

The seed weight was recorded using an electronic balance, and the mean was calculated and expressed in milligram (mg).

3.3.4. Biochemical parameters

3.3.4.1. Total soluble solids (%)

The total soluble solids were recorded using a digital hand refractometer adjusted at 20 ^{0}C and expressed as %.

3.3.4.2 Titratable acidity

The acidity was determined by an anhydrous citric acid by nitrogen the dilute juice against 0.1N sodium hydroxide by using phenolphthalein indicator (A.O.A.C, 1975). Formula: 1 ml of 0.1 N NaOH = 0.0064 g of citric acid was employed.

Acidity (%) = 00.0064 x Burette reading.

3.3.4.3 Ascorbic acid (mg/100g juice)

Ascorbic acid present in the fruit was estimated and expressed in terms of a milligram of ascorbic acid/100g of fruit pulp using the method described by Ranganna (1986).

$$\text{Ascorbic acid} = \frac{\text{Titrate (ml) x Dye factor x Volume made up (ml)}}{\text{Aliquot (ml) x Weight of juice (ml)}} \text{x } 100$$

3.3.4.4. Total sugars (%)

Total sugars were estimated by Ranganna (1986) the same method as that of reducing sugars. For this, using35 per cent hydrochloric acid (HCL) and hydrolyzed for half an hour in hot water. After hydrolyzing, sodium carbonate (40%) was used for acid neutralization. It was then titrated with Fehling A and Fehling B solutions using methyl blue as an indicator.

$$\text{Total sugars (\%)} = \frac{\text{250 ml}}{\text{Burette reading}} \text{ X } 100$$

3.3.4.5 Reducing sugars (%)

The reducing sugars from juice were estimated as per the method described by Ranganna (1986) and expressed in percentage.

3.3.4.6 Non-reducing sugars (%)

It was calculated by subtracting the volume of the reducing sugars from total sugars of the juice from each sample separately.

3.4. Statistical analysis

The data collected on morphology, physical parameters and quality characters were subjected to statistical analysis as per the methods suggested by Panse and Sukhatme (1954).

Plate No. 1: Captured during field trial (research activities), sample collection and lab analysis.

Plate No.2: Sample fruits of different treatments

CHAPTER IV

RESULTS AND DISCUSSION

In the succeeding pages, the experimental results of the present investigation have been presented and illustrated diagrammatically wherever necessary. Analysis of variance of various characteristics is presented in the appendices at the end. Data interpreted in the results with regards to the increase in plant height (m),the north-south direction of canopy spread (m), the east-west direction of canopy spread (m), girth (cm), number of flowers /meter shoot length, number of fruits/meter shoot length, percentage of fruit set, No. of fruit set in the north-south direction, No. of fruit set in the east-west direction, percentage of fruit drop, number of fruit s per plant, fruit yield (kg) per plant, fruit yield (ton/ha), fruit length (mm), fruit breadth(mm), juice content (%), fruit volume, peel thickness(mm), number of seeds fruit $^{-1}$, seed weight, total soluble solids (%), titratable acidity, total sugars, reducing sugars(%), non-reducing sugars (%)been presented under the following heads.

4.1. Morphological parameters

It is evident from the data furnished in table 4.1.1 that different growth regulating treatments had notable effects on morphological characters of acid lime plants viz., plant height, the north-south direction of canopy spread (m), the east-west direction of canopy spread (m) and girth (cm).

4.1.1. Plant biometric vegetative characters

The data on plant height and other biometric vegetative characters were recorded before the imposition of treatments to ensure that the plant material selected for the study was uniform. A perusal of data presented in table 4.1.1 and fig 2.1 revealed that various biometric plant parameters viz. height of the plant, the north-south direction of canopy spread, the effect of treatments on the east-west direction of canopy spread and girth were found non-significant indicating that the plant material taken for experimentation was uniform.

Table 4.1.1. Plant biometric vegetative characters of experimental plant material of acid lime.

Treatments	Plant height(m)	Canopy spread (m)		Stem girth (cm)
		North-south	East-west	
T_1 –Jasmonicacid@1 ppm	3.20	3.33	2.97	16.72
T_2 - Jasmonic acid @ 2 ppm	2.95	2.97	3	16.60
T_3 - Jasmonic acid @ 3 ppm	3.05	3.15	3.02	17.13
T_4 - Brassinosteroid@ 5 ppm	3.20	3.13	3.08	16.92
T_5 –Brassinosteroid @ 10 ppm	2.68	2.83	3.12	16.18
T_6 - Brassinosteroid@15 ppm	2.95	2.97	2.85	16.28
T_7 - GA_3@15 ppm + Urea 1%	2.60	2.75	2.72	15.68
T_8 - 2,4 -D @15 ppm + Urea 1%	2.80	3.27	3.25	16.40
T_9 - GA_3@15 ppm + KNO_3 1%	2.63	2.68	2.43	16.43
T_{10} -2,4 -D @15 ppm + KNO_3 1%	2.73	3.02	3.10	15.92
T_{11} - GA_3 @15 ppm + KH_2PO_4 1%	3.17	2.98	2.85	15.97
T_{12} -2,4 -D @15 ppm + KH_2PO_4 1%	2.68	2.80	2.73	16.82
T_{13} - Control	2.77	2.72	2.68	15.95
SE ± (m)	-	-	-	-
CD at 5%	NS	NS	NS	NS

4.2. Yield attributing parameters

It is evident from the data presented in table 4.1.2 that the combinations of growth hormones and nutrients influence the plant performance in terms of stability and yield viz. number of flowers per meter shoot length, number of fruit s per meter shoot length, fruit set (%), No. of fruit set in the north-south and the east-west direction, fruit drop (%), number of fruits per plant, fruit yield per plant (kg), fruit yield (t ha^{-1}), fruit retention (%).

4.2.1. Number of flowers per meter shoot length

A perusal of data presented in table 4.1.3 and figure 4.2 reveals that the number of flowers per meter shoot length was found to be non-significantly influenced by the application of crop regulation treatments, however, the maximum number of flowers (164.36) per meter shoot length was found in treatment T_5 – Brassinosteroid @10 ppm and the minimum number of flowers(117.36) per meter shoot length was found in treatment T_{10} -2,4 –D @ 15 ppm + KNO_3 1%.

The maximum number of flowers (164.36) per meter shoot length observed in treatment T_5-Brassinosteroid @10 ppm may probably be due to brassinosteroid's enhanced expression activity and protein stability which is blue-light dependent. Brassinosteroids may coordinate with light signaling in the control of the floral transition. Brassinosteroid signaling integrates with environmental cues to fine-tune the time of flowering through the flowering pathway and it is also found that brassinosteroids are also critical for floral transition, inflorescence, elongation of stigma, stem architecture formation and other aspects of plant reproductive processes (Zicong Li and Yuehui He,2020).

4.2.2. No of fruits per meter shoot length

The perusal of data presented in table 4.1.3 revealed that the foliar application of growth regulation treatments did not influence the no of fruits per meter shoot length. Whereas the highest no of fruits per meter shoot length was recorded in T_{10} -2,4 –D @15 ppm + KNO_3 1% and lowest in T_4 – Brassinosteroid @ 5 ppm.

4.2.3. Fruit set (%)

The analysis of data on fruit set percentage revealed the significant variation ($P < 0.05$) as observed in treatments. The maximum fruit set (20.98 %) was observed in treatment T_3-Jasmonic acid @ 3 ppm followed by treatment T_7 – GA_3 @ 15 ppm + Urea 1% (18.83%). The minimum fruit set (11.43 %) was observed in treatment T_9 – GA_3 @ 15 ppm + KNO_3 1% which was found on par with control T_{13} (11.41). The jasmonic acid is considered as an endogenous growth substance identified in many plant species which influence a wide variety of physiological and developmental responses (Parthier *et al.*1992). As a response to light, phytochrome and cryptochrome induce transduction signals to influence the jasmonate signaling pathway triggering developmental responses in plants (Kazan and manners, 2011).

In perennial crops stresses negatively affect growth through stomatal closure, which in turn disrupt photosynthesis as well as water and hormonal movement within the plant, bringing on a hormonal imbalance which leads the slowing of plant growth. Jasmonic acid is usually involved in physiological and molecular responses often including activation of the antioxidant system (superoxide anion radical, peroxidase and NADPH-oxidase) as reported by Karpets *et al.* (2014), accumulation of amino acids (isoleucine and methionine) and soluble sugars Wasternack *et al*. (2014) and regulation of the stomatal opening and closing (Acharya, B.R *et al.* 2009).

Omima *et al*. (2014), also observed that the foliar spray of jasmonic acid@15 ppm and 25 ppm on Olive tree significantly increased fruit set, yield and quality traits.

4.2.4. No. of fruit set in the north-south direction

The effect of treatments on fruit set in north-south direction was found non-significant as presented in table 4.1.2 and depicted in fig 4.2 However, the maximum increase in north-south direction fruit set (740) was found in treatment T_3 – Jasmonic acid @ 3 ppm and the minimum fruit set (413) was found in treatment T_1 – Jasmonic acid @1 ppm, which was observed on par with control T_{13} (412). These observations were in conformity with those reported by Parthier *et al.* (1992).

4.2.5. No. of fruit set in the east-west direction

The data presented in table 4.1.3 and fig 4.2 was found to be statistically non-significant. Maximum fruit set (612.0) in east-west direction was found in treatment T_7-GA_3@ 15ppm + Urea 1% and minimum (289.0) was observed in treatment control T_{13}.A similar result was reported by Parthier *et al.* (1992). A combination of growth hormones and nutrient influences the plant performance in terms of stability and yield like nitrogen affects the absorption and distribution of practically all other nutrients in the plant and is particularly important during flowering and fruit set. The growth-active hormones together with a nitrogen-based fertilizer can result in appreciable and significant additive increases in reproductive yield Zaman, M *et al.* (2014) and Neha Patel and S. K. Pandey (2012).

4.2.6. Fruit drop (%)

The data regarding fruit drop presented in table 4.1.3 and figure 4.2 revealed that the application of growth-regulating hormones and nutrients significantly influenced the fruit drop. The observed data showed that foliar application of T_{10} - 2,4 –D @ 15 ppm + KNO_3 1% recorded the lowest fruit drop (37.88 %) over control.

However, treatments T_6-Brassinosteroid @ 15 ppm (43%), T_3 – Jasmonic acid @ 3 ppm (44.81%) and T_9 -GA_3 @ 15 ppm + KNO_3 1% (46.08%) showed moderate fruit drop respectively. This may be because of the contribution of potassium nitrate along with the growth regulator. The quality improvement in fruits may be due to the proper supply of nutrients and induction of growth hormones, which stimulates cell division, cell elongation, increase in weight of fruits, better translocation of water uptake and deposition of nutrients. These findings are in close conformity with the findings of Modise *et al.* (2009) who observed that the application of 2,4-D 16 and 20 mg/L was effective to control fruit drop by enhanced retention, as well as improving the quality of navel oranges under dry climatic conditions.

4.2.7. Number of fruits per plant

Data on the number of fruits per plant gave significant variation and the same is presented in table 4.1.3 and fig 4.2. Significantly maximum number of fruits/plants was recorded by treatment T_3-Jasmonic acid @ 3 ppm (1234) followed by treatments T_7 – GA_3 @ 15 ppm + Urea 1%, (1134) and T_6-Brassinosteroid @ 15 ppm, (1089). However, treatments T_4-Bassinosteroid @ 5ppm and T_1-Jasmonic acid @1ppmwere found on par with control (702).

The above findings of Garcia-Pastor *et al.* (2019) also revealed significantly increased pomegranate crop yield with the application of MeJA at 1 and 5 mmol L^{-1}. Ali and Zayat (2019) recorded that the 4ml/L of jasmine oil is more effective on fruit set, significantly increased no. of fruit /plant and yield per plant in Washington Navel Orange. The obtained results regarding the effect of jasmonic acid on fruit set go line with the findings of Oliva *et al*. (1988) and Fugisawa *et al.*(1997).

4.2.8. Fruit weight (g)

A perusal of data presented in table 4.1.3 and fig 4.2 revealed that different growth regulating treatments significantly influenced the fruit weight. Treatment T_6-Brassinosteroid @ 15 ppm (52.36 g) exhibited the maximum fruit weight followed by treatments T_{3-} Jasmonic acid 3@ppm (50.26 g), T_5-Brassinosteroid @ 10 ppm(49.91 g), T_{4-} Bassinosteroid @ 5ppm (49.31 g), T_{7-} GA_3 @ 15 ppm + Urea 1%)(48.35 g), and the treatments T_9 –GA_3 @ 15 ppm+ KNO_3 1) T_{10} – 2,4-D@ 15ppm+KNO_3 1%), T_{2-} Jasmonic acid @ 2ppm, T_{1-} Jasmonic acid @1ppm, T_{12-} 2,4-

D @ 15ppm+ Monopotassium phosphate 1%), T_8-2,4 –D 15 ppm + Urea 1%were found on par with control. The above resuts might be due to exogenious application brassinosteroid increased fruit weight in sweet cherries fruits Baghe *et al*., (2019).

Further, Eid *et al*. (2016) revealed that foliar application of Milagro (0.2% Brassinolide) increased fruit weight of avocado tree cv. Fuerte. Also, Bhat *et al.* (2011) observed that brassinosteroid 0.4 mg /L give the highest bunch and berry weight due to the increased assimilation efficiency of photosynthetic carbon, however, brassinosteroid stimulate greater Co_2 assimilation and increased cell division. BRs exogenous application in an aqueous solution considerably enhanced grape cluster weight and berry weight, (Champa *et al.* 2015). BR might be involved in initial fruit development by stimulating cell division of strawberry fruits. It was also validated by downregulating the expression of BRs receptors Chai *et al.* (2013).

Similar results were also recorded by Baghel *et al*. (2019) in navel orange and Laila *et al*. (2018) in sugars apple fruit trees.

4.2.9. Fruit yield per plant (kg)

The observed yield per plant (kg) of acid lime was significantly influenced by the foliar application of different treatments as presented in table 4.1.3 and fig 4.2. The data revealed that the fruit yield per plant was significantly influenced by the growth-regulating treatments. The treatment T_3-Jasmonic acid @ 3 ppm (62.02 kg) was found significant followed by treatments T_6-Brassinosteroid @15 ppm (57.02 kg) and T_7-GA_3 @ 15 ppm + Urea 1% (84.83 kg) respectively, whereas treatment T_1-Jasmonic acid@ 1 ppm (28.34 kg) was found on par with control T_{13} (25.95). Similar results were observed by Martinaze-Espla *et al*. (2014) and Jagtap *et al.* (2013).

4.2.10. Fruit yield (t ha^{-1})

The data regarding fruit yield (t ha^{-1}) was found statistically significant as presented in table 4.1.3 and fig 4.2. It was evident that the application of plant growth regulating treatments significantly affected the yield of acid lime. The maximum yield (17.18t ha^{-1}) was obtained in (foliar spray of T_3Jasmonic acid @ 3 ppm in the months of February, March and April) followed by treatmentsT_6 – Brassinosteroid @15 ppm (15.79 t ha^{-1}) and T_7 – GA_3@ 15 ppm + Urea 1% (15.19t ha^{-1}) and minimum yield recorded in control (7.19t ha^{-1}). All remaining treatments showed a moderate increase in fruit yield t ha^{-1}over control.

The above findings are found in line with the findings of Garcia-Pastor *et al.* (2019) revealed that the significantly increased pomegranate crop yield, application of MeJA at 1 and 5 mmol L^{-1}.

4.2.11. Grade wise yield of acid lime

Fruit size distribution in response to different treatments was also recorded and classified as Grade A (50-55 g), Grade B (40-50 g) and Grade C (30-40 g). The data presented in table 4.1.2 and fig 1.1 showed significant variation among the grades. The data revealed that the maximum percentage (37.12 %) of fruit having weight 50-55 g (Grade A) was obtained in treatment T_3-Jasmonic acid @ 3 ppm, however, in grade B maximum was recorded in treatment T_8-2,4 –D @ 15 ppm + Urea 1%) and in Grade C treatment T_4-Brassinosteroid @ 5 ppm showed the maximum percentage of fruits (48.27%). The higher-grade size was obtained with treatments T_3-Jasmonic acid@3 ppm, T_8 -2,4 –D @15 ppm + Urea 1%and T_4-Brassinosteroid @5 ppm respectively with compared to other treatments. Larger size fruit fetches premium prices in the market and getting the maximum size of the fruits is of high economic significance to raise the income of the citrus growers.

Table 4.1.2. Effect of crop regulating treatments on the graded yield of acid lime

Treatments	Grade-A	Grade -B	Grade-C
	% of fruits having weight 50-55 g	% of fruits having weight 40-50 g	% of fruits having weight 30-40 g
T_1-Jasmonic acid @ 1 ppm	21.81	39.63	38.56
T_2-Jasmonic acid @ 2 ppm	20.74	36.96	42.30
T_3-Jasmonic acid @ 3 ppm	37.12	43.84	19.04
T_4-Brassinosteroid @ 5 ppm	21.91	29.82	48.27
T_5Brassinosteroid @10 ppm	23.85	31.40	44.75
T_6-Brassinosteroid @15 ppm	31.31	39.39	29.29
T_7-GA_3@15 ppm + Urea 1%	35.36	37.13	27.51
T_8-2,4 –D@ 15 ppm + Urea 1%	24.79	48.46	26.75
T_9-GA_3@15 ppm + KNO_3 1%	32.02	40.51	27.47
T_{10}-2,4 –D@ 15 ppm + KNO_3 1%	30.13	39.94	29.93
T_{11}-GA_3 @15 ppm + KH_2PO_4 1%	20.08	35.66	44.26
T_{12}-2,4 –D @ 15 ppm + KH_2PO_4 1%	23.02	34.37	42.61
T_{13}-Control	26.35	34.90	38.75
SE ± (m)	**2.57**	**3.50**	**3.20**
CD at 5%	**5.31**	**7.22**	**6.60**

4.2.12. Fruit retention (%)

A perusal of data presented in table 4.1.3 and fig 4.3 reveals that different treatments significantly influenced the fruit retention of acid lime. It was evident from the data that treatment T_{10}-2,4–D @ 15 ppm + KNO_3 1% showed maximum percentage of fruit retention (62.12 %) followed by treatments T_6-Brassinosteroid @15 ppm (56.90%), T_3-Jasmonic acid @ 3 ppm (55.19%), T_9-GA_3 @15 ppm + $KNO_3$1% (53.92%) and T_7-GA_3 @15 ppm + Urea 1% (52.99%) respectively over control (37.34 %). However, the treatments T_1- Jasmonic acid @ 1 ppm (37.34) and T_4-Brassinosteroid @ 5 ppm (43.12) were found on par with control. The above findings are found in line with the result recorded by Neha Patel and S.K. Pandey (2012). Similarly, Thirugnanavel *et al*. (2007) found that the application of KNO_3 2% significantly enhanced fruit retention and yield in acid lime.

Table 4.1.3. Effect of growth regulators on yield attributes of acid lime

Treatments	Number of flowers /meter shoot length	Number of fruits/meter shoot length	Fruit set (%)	No. of fruit set in the north-south direction	No. of fruit set in the east-west direction	% fruit drop	No. of fruits per plant	Fruit weight (g)	Fruit yield per plant (kg)	Fruit yield (tonne/ ha)	Fruit retention (%)
T_1 –Jasmonicacid @ 1 ppm	126.23	26.22	16.06	412	340	62.66	752	37.69	28.34	7.85	37.34
T_2 – Jasmonic acid @ 2 ppm	142.69	29.18	16.64	548	426	49.74	974	39.69	38.66	10.71	50.26
T_3 – Jasmonic acid @ 3 ppm	151.85	31.11	20.98	740	494	44.81	1234	50.26	62.02	17.18	55.19
T_4 – Brassinosteroid @ 5 ppm	147.69	22.10	13.53	412	309	56.88	721	49.31	35.55	9.85	43.12
T_5 – Brassinosteroid @10 ppm	164.36	29.56	14.81	485	429	50.08	914	49.91	45.62	12.64	49.92
T_6 – Brassinosteroid @15 ppm	152.29	26.12	16.59	617	472	43.10	1089	52.36	57.02	15.79	56.90
T_7 – GA_3@15 ppm + Urea 1%	137.21	24.15	18.83	522	612	47.01	1134	48.35	54.83	15.19	52.99
T_8 – 2,4 –D @15 ppm + Urea 1%	141.36	22.84	13.01	514	458	48.68	972	35.74	34.74	9.62	51.32
T_9 – GA_3@15 ppm + KNO_3 1%	136.84	26.42	11.36	601	411	46.08	1012	41.65	42.15	11.68	53.92
T_{10} -2,4 –D @15 ppm + KNO_3 1%	117.36	34.12	13.10	452	537	37.88	989	39.91	39.47	10.93	62.12
T_{11} – GA_3 @15 ppm + KH_2PO_4 1%	137.97	24.26	14.58	631	370	49.85	1001	42.36	42.40	11.75	50.15
T_{12} -2,4 –D @15 ppm + KH_2PO_4 1%	124.78	22.47	12.26	528	406	47.68	934	37.58	35.10	9.72	52.32
T_{13} – Control	142.36	22.54	11.41	413	289	60.65	702	36.97	25.95	7.19	39.35
SE ± (m)	-	-	1.01	-	-	3.20	63.30	2.83	2.87	0.79	3.26
CD at 5%	NS	NS	2.97	NS	NS	9.36	184.78	8.28	8.40	2.32	9.53

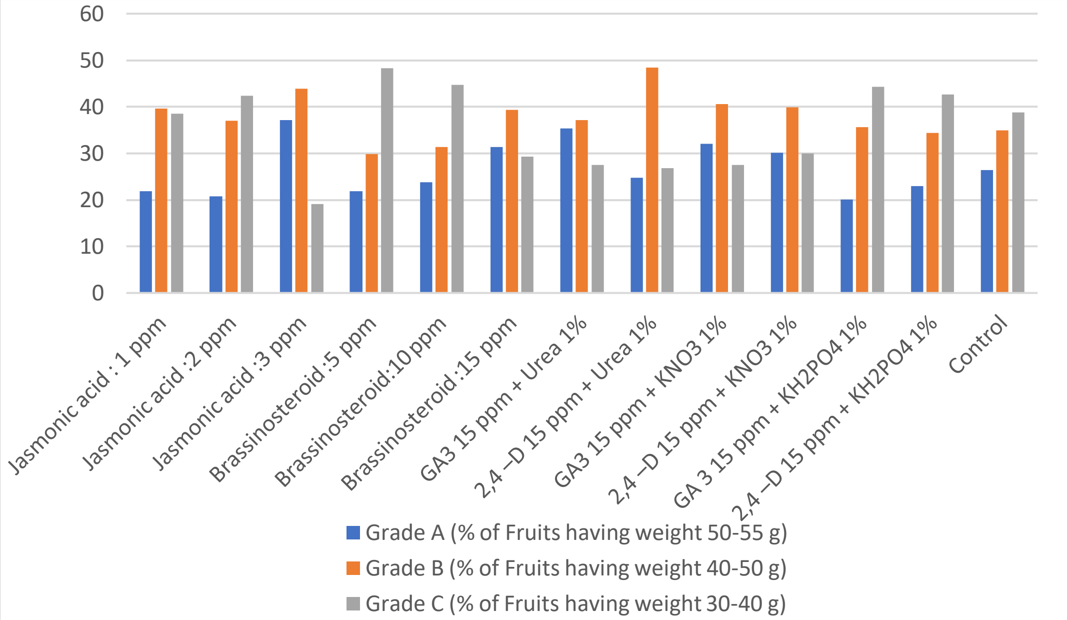

Fig. 4.1- Effect of crop regulating treatments on Graded yield parameter of acid lime

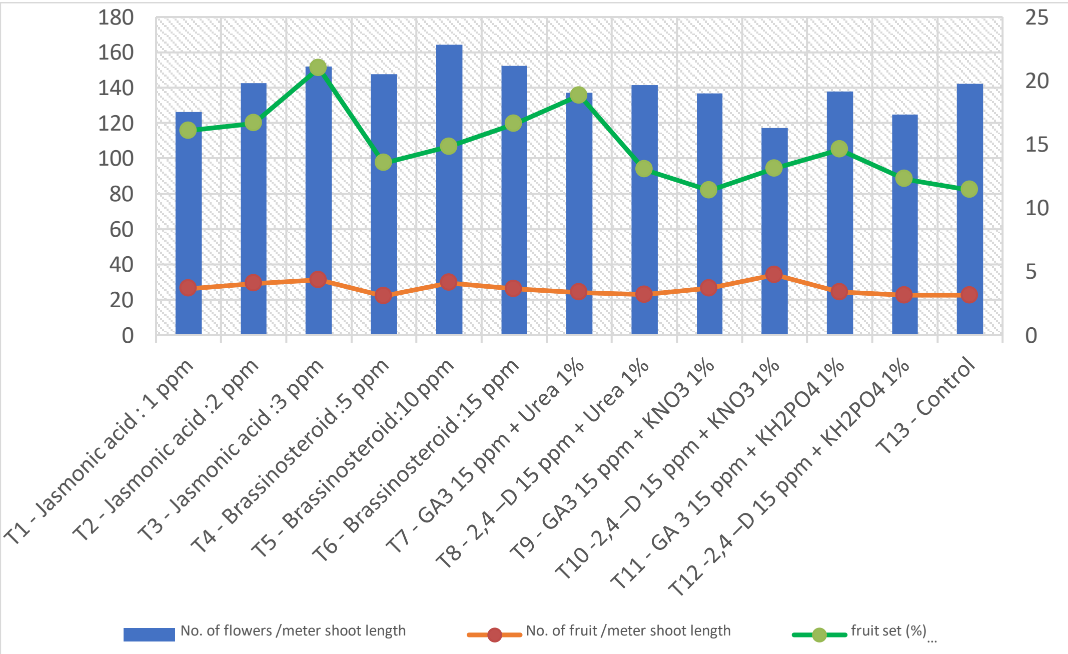

Figure 4.2 -Effect of growth regulation treatments on no. of flowers meter^{-1} shoot length, no. of fruit meter^{-1} shoot length and fruit set % parameters of acid lime

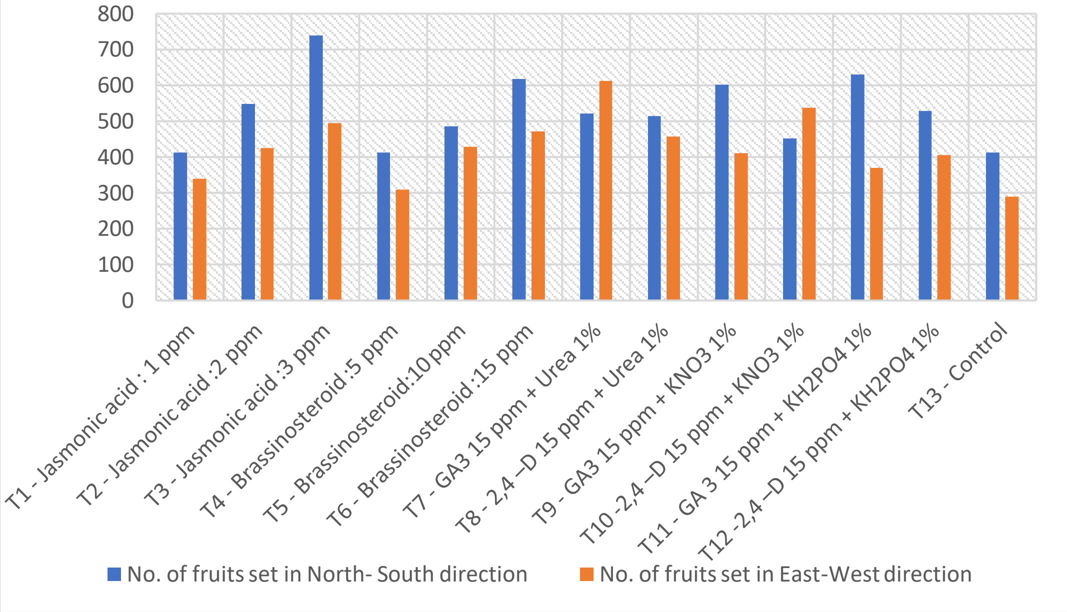

Figure 4.3 -Effect of growth-regulating treatments on no. of fruit set in the north-south direction and no. of fruit set in east-west direction parameters of acid lime

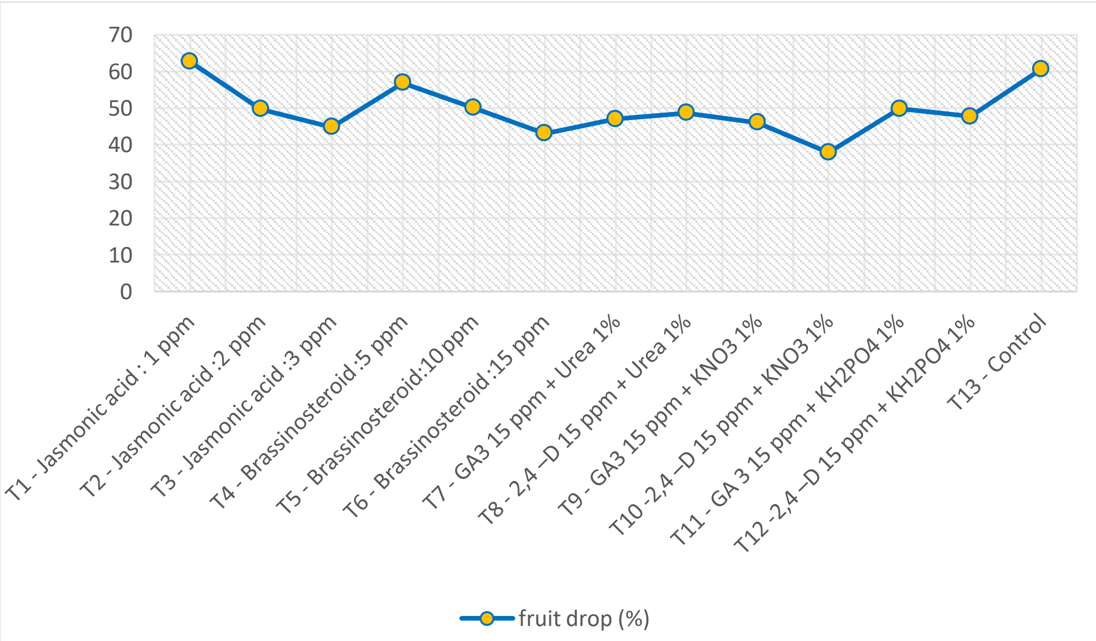

Figure 4.4 -Effect of growth-regulating treatments on fruit drop % parameters of acid lime

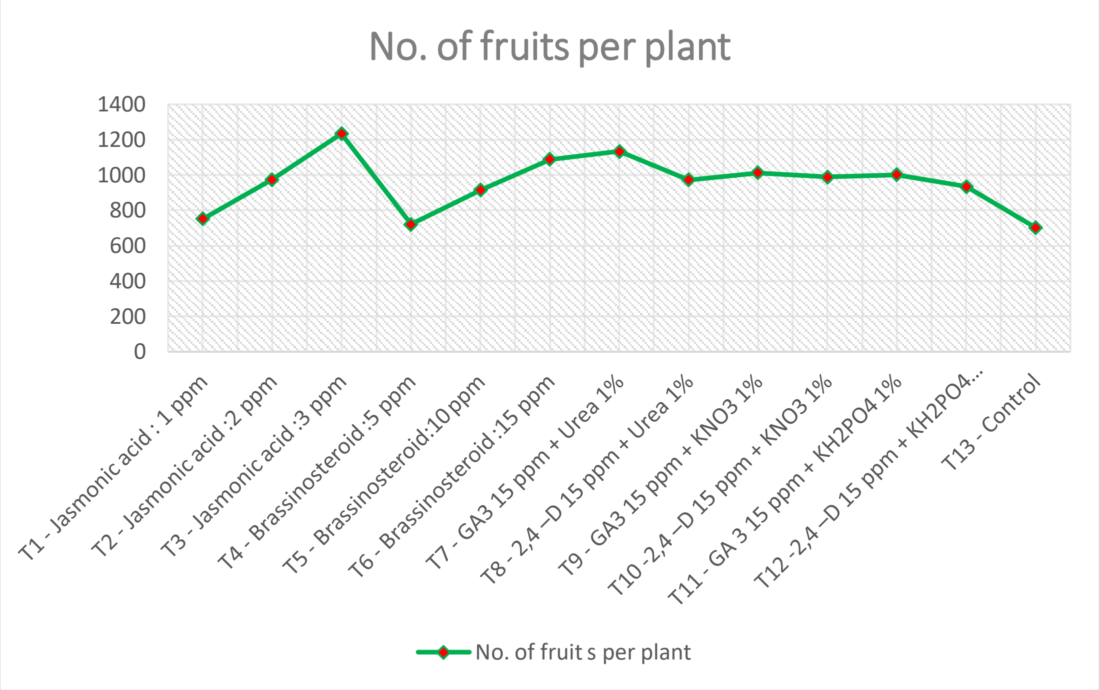

Figure 4.5 -Effect of growth-regulating treatments on the number of fruits per plant parameters of acid lime

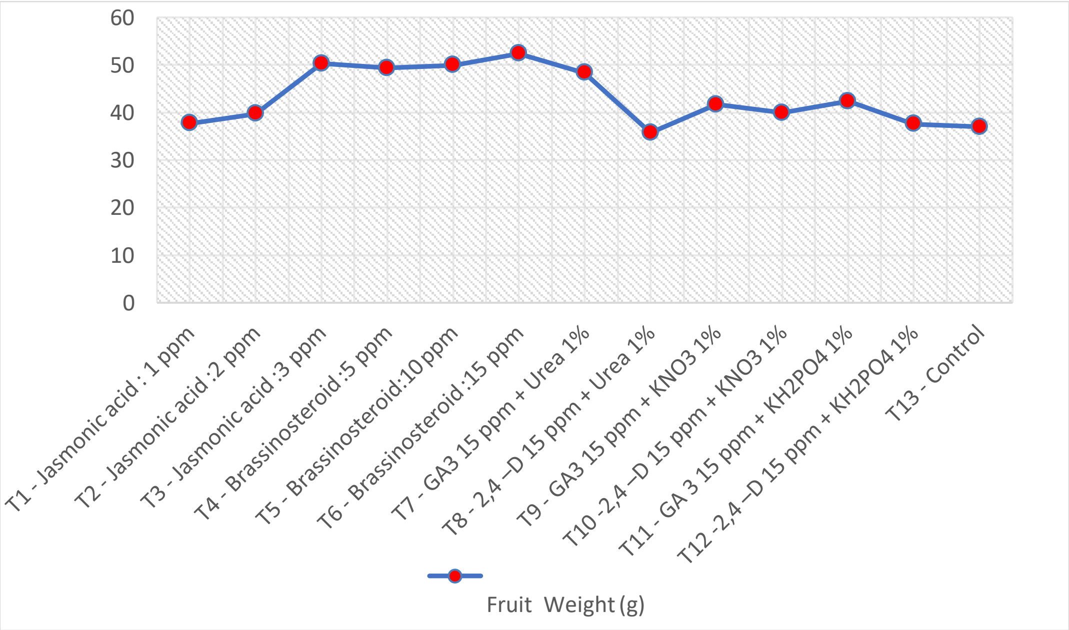

Fig. 4.6- Effect of crop regulating treatments on fruit weight parameter of acid lime

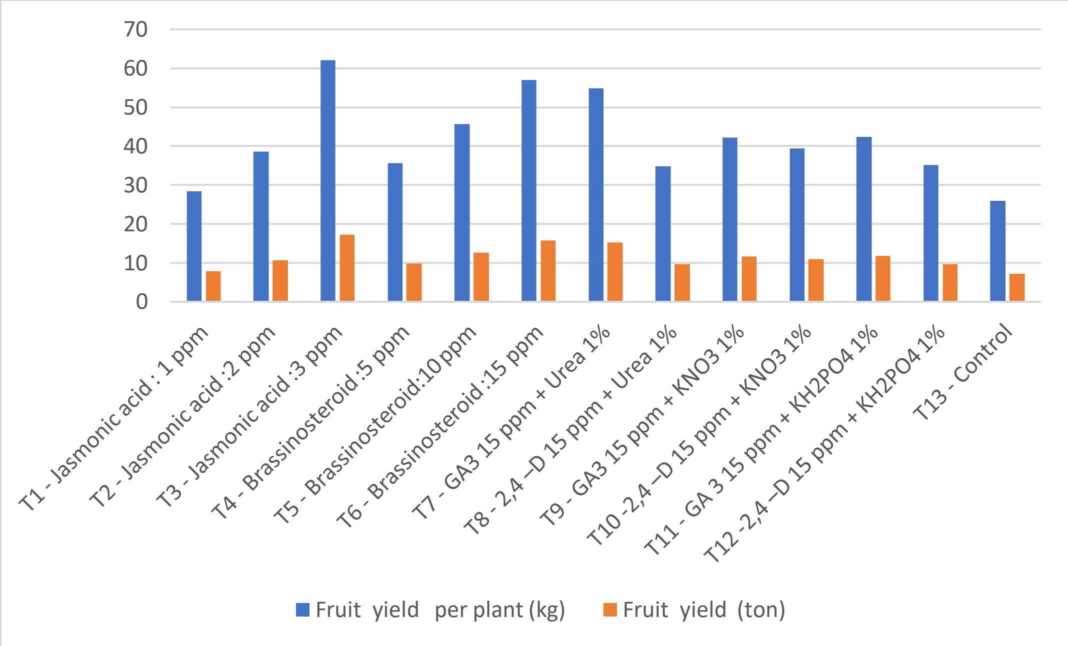

Fig. 4.7- Effect of crop regulating treatments on fruit yield plant^{-1} and fruit yield (ton) parameters of acid lime

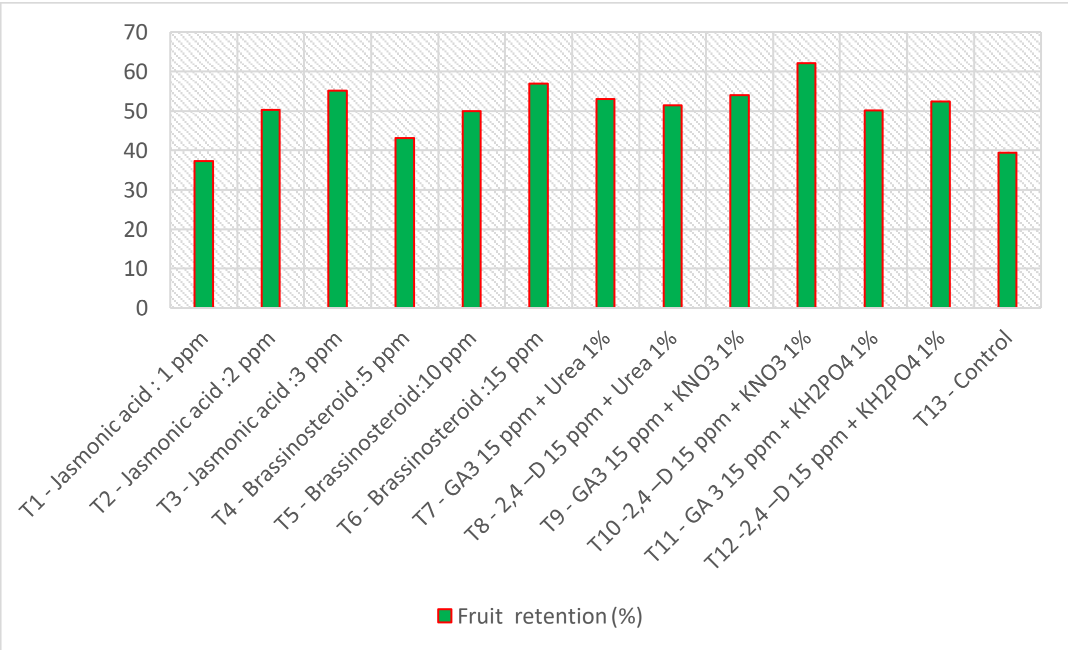

Fig. 4.8 Effect of crop regulating treatments on fruit retention of acid lime

4.3. Physical parameters:

The results obtained in the present study showed that application of plant growth hormones and nutrients significantly enhanced and improved the physical characters of acid lime in terms of fruit length (mm), fruit breadth (mm), fruit volume (cc), peel thickness (mm), peel percentage, number of seeds fruit $^{-1}$, seed weight (g) as compared to control.

4.3.1. Fruit length (mm)

The data regarding fruit length presented in table 4 and fig4.3 differed significantly over control. The maximum fruit length (35.20 mm) was found in T_7 - GA_3 15 ppm + Urea 1% followed by treatment T_5– Brassinosteroid @ 10 ppm, (35.18mm). All remaining treatments showed a moderate increase in fruit length over control.

It is noticeable from the results presented in table 4 and fig 4.3 that fruit length was maximum in treatment T_7- GA_3 @15 ppm + Urea 1% (35.20 mm) as compared to control. Similar results were recorded by Bradford *et al.* (2003) and Bharti *et al.* (2019) in acid lime. Jasmonic acid (JA) or its derivatives have been found to occur naturally in a wide range of higher plants and considered as elicitors or signaling agents involved in many physiological and biochemical processes Creelman and Mullet,(1997).

4.3.2. Fruit breadth (mm)

A perusal of data regarding fruit breadth (mm) of acid lime showed that the fruit breadth was significantly influenced by the application of different treatments as summarized in table 4 and fig 4.3 The maximum fruit breadth (31.36 mm) was found in treatment T_3-Jasmonic acid @ 3ppm followed by treatment T_6-Brassinosteroid @ 15 ppm (31.23mm) over control.

Among the treatments, maximum fruit breadth (31.36 mm) was recorded in the application of T_3-Jasmonic acid @ 3ppm and followed by T_6- Brassinosteroid @ 15 ppm (31.23 mm) compared to the control. Ali and Zayat (2019) in Washington

Navel orange, Thapliyal *et al.* (2016) in pear and Laila *et al*. (2018) in sugar apple also observed similar results.

4.3.3. Juice content (%)

The perusal of data regarding juice content (%) presented in table 4 and fig 4.3 was significantly influenced by the foliar application of crop growth regulation treatments. The maximum juice content (46.16 %) was recorded in T_3 - Jasmonic acid @ 3 ppm and minimum (40.36 %) in T_9 - GA_3@15 ppm + KNO_3 1%.

The above findings are found in line with the findings of Mohammadreza Asghari *et al*. (2019).

4.3.4. Fruit volume (cc)

The perusal of data regarding fruit volume (cc) presented in table 4 and fig 4.3 was significantly influenced by the foliar application of crop growth regulation treatments. The maximum fruit volume (52.65 cc) was recorded in treatment T_3 - Jasmonic acid @ 3 ppm followed by treatments T_6- Brassinosteroid @ 15 ppm (50.11 cc), T_7- GA_3 15 ppm + Urea 1% (49.47 cc), T_5-Brassinosteroid @ 10 ppm (47.25 cc) and T_4-Brassinosteroid @ 5 ppm (46.74 cc) respectively. However, all remaining treatments were found on par with control (38.04cc) and minimum fruit volume was recorded in T_8-2,4 –D 15 ppm + Urea 1% (36.31 cc).

In line with this Martinez-Espla *et al.*(2014), reported that fruit volume was significantly affected by MeJA treatments in BS plums with the concentration of 0.5 and 1 mM MeJA led to significantly ($P < 0.05$) higher fruit volume than in the control, the concentrations of 0.5 and 2.0 mM were also effective in significantly increasing the fruit volume at harvesttime, the major increases in fruit volume were 8 and 18% in 0.5 and2.0 mM treated plums for BS and RR, respectively. Yilmaz. H *et al.* (2003) reported that foliar feed of jasmonic acid (0.25, 0.50 and 1 mM) on strawberry, significantly increased berry size in the first two weeks of harvest, and increased total yield per plant.

4.3.5. Peel thickness (mm)

The recorded data regarding peel thickness (mm) presented in table 4 and fig 4.3 found non-significant among different treatments. The maximum peel thickness

(1.76 mm) was found in treatment T_3- Jasmonic acid @ 3ppm and minimum (1.54 mm) was found in T_4-Brassinosteroid @5 ppm and all remaining treatments exhibited a moderate increase in peel thickness over control.

4.3.6. Peel percentage

The data regarding peel percentage presented in table 4.1.4 and fig 4.3 was found to be non-significant. However, the maximum peel percentage (19.18 %) was found in treatment T_1 - Jasmonic acid @ 1 ppm and the minimum (15.41%) was in treatment T_4 - Brassinosteroid @ 5 ppm.

4.3.7. Number of seeds fruit $^{-1}$

A perusal of data presented in table 4.1.4 and fig 4.3 revealed that the number of seeds fruit $^{-1}$ was significantly influenced by different crop regulation treatments. Maximum number of seeds/fruit was found in treatment T_7- GA_3 @ 15 ppm + Urea 1% (11.15) followed by treatments T_{10}-2,4 –D @15 ppm + KNO_3 1% (10.74), T_{12}-GA_3 @15 ppm + KH_2PO_4 1% (10.66), T_9- GA_3@15 ppm + KNO_3 1% (10.47), T_6–Brassinosteroid @15 ppm (10.21) respectively. Further, the combination of growth regulation treatment T_7- GA_3 @15 ppm + Urea 1% exhibited the highest (11.15) number of seeds fruit^{-1}over all the treatments. Bradford *et al.* (2003) indicated that the regulation of LeSNF4 expression by GA_3 provides a potential link between hormonal and sugars -sensing pathways controlling seed development.

4.3.8. Seed weight (g)

The data related to seed weight (g) of acid lime fruit is presented in table 4.1.4 and fig 4.3. The seed weight did not influence significantly by different crop regulation treatments. However maximum (1.32 g) seed weight was found in treatment T_7- GA_3 @15 ppm + Urea 1% and minimum in control (1.23 g).

Table 4.1.4-Effect of growth regulator on physical parameters of acid lime

Treatments	Fruit length (mm)	Fruit breadth (mm)	Juice content (%)	Fruit volume (cc)	Peel thickness (mm)	Peel %	Number of seeds fruit $^{-1}$	Seed weight (g)
T_1 - Jasmonicacid @ 1 ppm	31.20	28.36	41.39	39.56	1.58	19.18	9.20	1.25
T_2 - Jasmonic acid @ 2 ppm	30.14	27.86	43.36	42.19	1.63	18.39	8.21	1.26
T_3 - Jasmonic acid @ 3 ppm	32.18	31.36	46.16	52.65	1.76	15.52	8.44	1.27
T_4 - Brassinosteroid @ 5 ppm	32.10	27.12	45.52	46.74	1.54	15.41	9.05	1.26
T_5 – Brassinosteroid@10 ppm	35.18	30.25	42.94	47.25	1.69	15.43	9.23	1.24
T_6 - Brassinosteroid @15 ppm	35	31.23	44.36	50.11	1.67	15.47	10.21	1.28
T_7 - GA_3@15 ppm + Urea 1%	35.20	30.23	45.95	49.47	1.68	15.51	11.15	1.32
T_8 - 2,4 –D@ 15 ppm + Urea 1%	33.84	29.18	42.87	36.31	1.58	19.03	8.45	1.24
T_9 - GA_3@15 ppm + KNO_3 1%	31.20	28.14	40.36	40.20	1.63	17.77	10.47	1.30
T_{10} -2,4 –D @15 ppm + KNO_3 1%	32.26	30.36	43.63	37.51	1.61	18.29	10.74	1.26
T_{11} - GA_3 @15 ppm + KH_2PO_4 1%	30.69	28.01	42.14	43.36	1.64	17.45	7.69	1.32
T_{12} -2,4 –D @15 ppm + KH_2PO_4 1%	33.41	29.37	44.36	37.89	1.59	17.80	10.66	1.28
T_{13} - Control	32.25	29.16	42.17	38.04	1.67	18.42	8.41	1.23
SE ± (m)	1.60	1.09	2.80	2.85	-	-	0.84	-
CD at 5%	4.96	3.18	8.18	8.32	NS	NS	1.73	NS

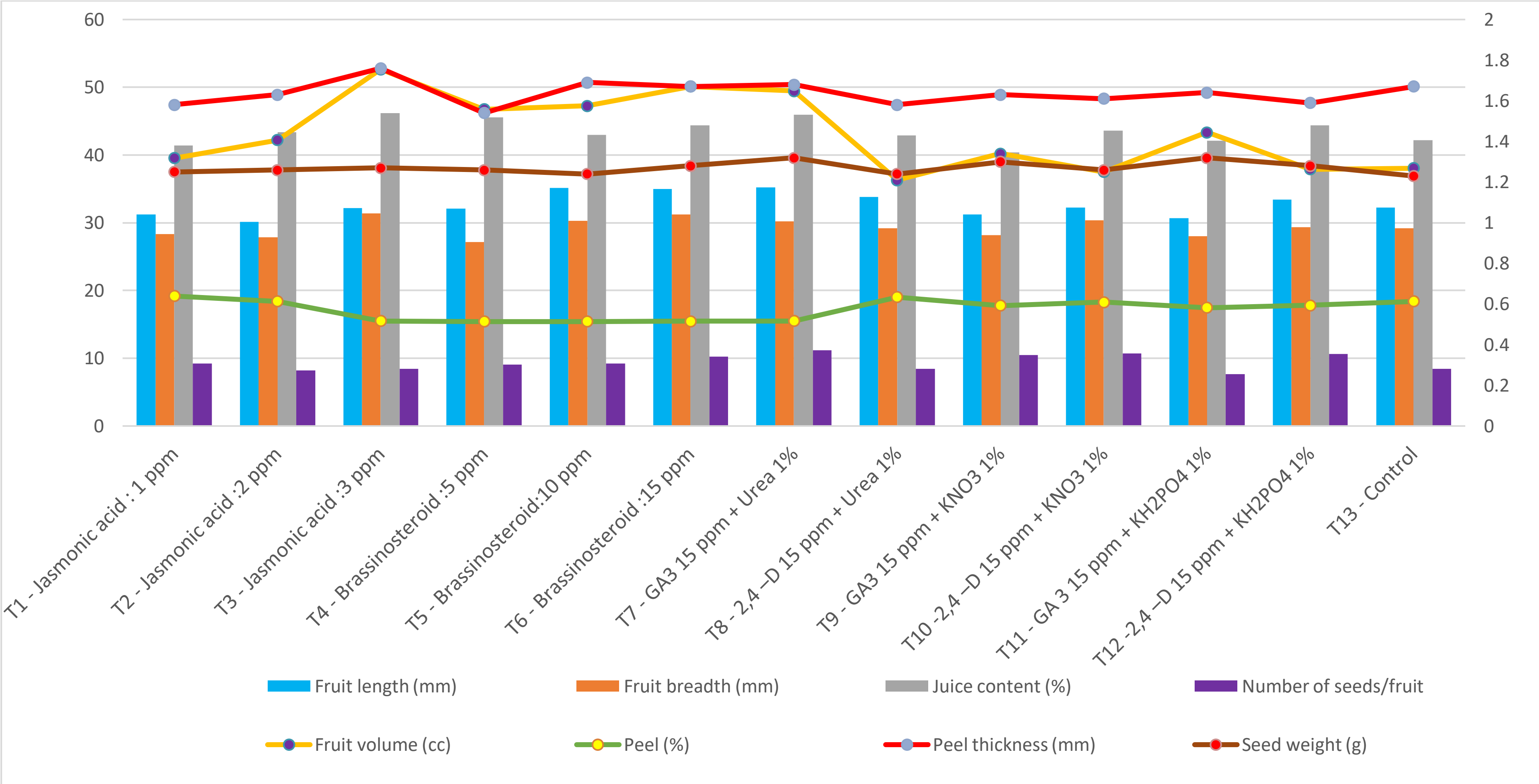

Fig.4.9 -Effect of growth regulating treatments on fruit length, fruit breadth, juice content, fruit volume, peel % and peel thickness of acid lime

4.4. Biochemical parameters

4.4.1.TSS (%)

The critical look at the data revealed that the effect of different treatment on "Total Soluble Solid" content of acid lime fruits was found to be significant (table 4.1.5 and fig 4.4). The maximum TSS (7.71 ^{0}B) was found in treatment T_7- GA_3 @ 15 ppm + Urea 1% followed by treatment T_3 - Jasmonic acid @ 3 ppm, (7.69 ^{0}B). whereas lowest TSS was found in T_{10}-2,4 –D 15 ppm + KNO_3 1% (7.41 ^{0}B) under control (7.47 ^{0}B). An increase in TSS in juice application of growth regulators with a combination of nutrients, GA_3 with the combination of urea could be a result of the increase in the enzymatic activity in the physiological processes of fruit growth. Similar results were recorded by Jagtap *et al.* (2013) in acid lime, Debaje *et al.* (2010) in acid lime and Deshlehra *et al.* (2019).

4.4.2. Titratable Acidity

It is evident from the data presented in table 4.1.5 and fig 4.4 that the titratable acidity was statistically significant. The maximum titratable acidity (7.50%) was found in treatment T_3- Jasmonic acid @ 3ppm followed by treatments T_7-GA_3 15 ppm + Urea 1% (7.36%) and T_6 -Brassinosteroid @15 ppm (7.30%) as compared to control.

Among the treatments, the maximum titratable acidity (7.50%) with the application of T_3-Jasmonic acid @ 3ppm was observed as compared to control (6.05%). The above results were found in agreement with the results of Fusawa *et al.* (1996) who recorded the highest acidity 0.77% and 0.69 % with jasmonic acid 300 ppm and 50 ppm in persimmon and apple respectively. Martines-Espla *et al.* (2014) also reported that the effect of MeJA treatment on plum cultivar was significant at harvest time for the 0.5 mM treatment, for which titratable acidity was significantly higher ($P < 0.05$) than in controls.

4.4.3. Ascorbic acid (mg/100 ml juice)

A perusal of the data presented in table 4.1.5 and depicted in fig 4.4 revealed that different crop regulation treatments significantly influenced the ascorbic acid content. The maximum ascorbic acid (30.10 mg/ 100g) was recorded in treatment T_7

- GA_3 @ 15 ppm + Urea 1% with minimum (26.32 mg) in treatment Brassinosteroid @ 5 ppm. Treatment T_9-GA_3@15 ppm + KNO_3 1% (26.74 mg) and T_4-Brassinosteroid @ 5 ppm (26.32 mg) were recorded minimum ascorbic acid under control (27.01).

Among the treatments, the maximum ascorbic acid (30.10 mg/ 100g) was recorded with application of GA_3 @ 15 ppm + Urea 1% compared to the control (27.01 mg/ 100g). Similar results were recorded by Debaje *et al.* (2010) in acid lime and Thapliyal *et al*. (2016) in sugars apple.

4.4.4. Total sugars (%)

The data on total sugars as influenced by crop growth regulation treatments are presented in table 4.1.5 and fig 4.4 the recorded data revealed that among the various treatments, significantly higher total sugars (1.27%) was recorded in treatment T_7 - GA_3 15 ppm + Urea 1%, and minimum in control (1.01%). However, all other treatments showed a moderate increase in total sugars over control.

Among the treatments, the maximum total sugars (1.27%) were recorded in GA_3 15@ ppm + Urea 1% and minimum in control (1.01%). Similar results were reported by Thapliyal *et al*. (2016).

4.4.5. Reducing sugars (%)

Data presented in table 4.1.5 and fig 4.4 revealed that there was a significant effect of crop growth regulation treatments on reducing sugars (%) over control. The maximum value of reducing sugars (0.84 %) was recorded under treatment T_7 - GA_3@15 ppm + Urea 1% and minimum (0.60 %) in control. Reducing sugars of T_7-GA_3@ 15 ppm + Urea 1%treatment registered (0.84 %) higher over control (T_{13}).

Among the treatments, the maximum reducing sugars (0.84%) were recorded with the application of GA_3 @15 ppm + Urea 1% as compared to control. Similar result was reported by Thapliyal *et al.*, 2016 in sugar apple.

4.4.6. Non-reducing sugars (%)

The data related to non-reducing sugars (%) in acid lime was significantly influenced by the application of different treatments presented in table 4.1.5 and fig 4.4.

The recorded data revealed that the maximum (0.51 %) non-reducing sugars were obtained in treatment T_1-Jasmonicacid @ 1 ppm whereas the minimum non-reducing sugars (0.39 %) was recorded under control.

Table. 4.1.5-Effect of crop regulating treatments on biochemical parameters of acid lime

Treatments	TSS (%)	Titratable acidity (%)	Ascorbic acid (mg/100 ml juice)	Total sugars (%)	Reducing sugars (%)	Non reducing sugars (%)
T_1 - Jasmonicacid@ 1 ppm	7.48	5.85	27.15	1.25	0.68	0.57
T_2 - Jasmonic acid @ 2 ppm	7.57	6.14	27.05	1.09	0.66	0.43
T_3 - Jasmonic acid @ 3 ppm	7.69	7.50	28.57	1.15	0.69	0.46
T_4 - Brassinosteroid@ 5 ppm	7.50	6.74	26.32	1.07	0.63	0.44
T_5 –Brassinosteroid @10 ppm	7.57	6.96	28.41	1.19	0.70	0.49
T_6 - Brassinosteroid@15 ppm	7.63	7.30	29.11	1.15	0.67	0.48
T_7 - GA_3@15 ppm + Urea 1%	7.71	7.36	30.10	1.27	0.84	0.43
T_8 - 2,4 –D @15 ppm + Urea 1%	7.46	6.54	28.26	1.03	0.64	0.39
T_9 - GA_3@15 ppm + KNO_3 1%	7.61	6.10	26.74	1.18	0.65	0.53
T_{10} -2,4 –D @15 ppm + KNO_3 1%	7.41	5.74	29.21	1.23	0.72	0.51
T_{11} - GA_3 @15 ppm + KH_2PO_4 1%	7.52	5.98	28.41	1.06	0.67	0.39
T_{12} -2,4 –D @15 ppm + KH_2PO_4 1%	7.58	6.12	28.39	1.09	0.62	0.47
T_{13} - Control	7.47	6.05	27.01	1.01	0.60	0.39
SE ± (m)	0.010	0.42	1.17	0.07	062	-
CD at 5%	0.029	1.22	3.43	0.21	0.0128	NS

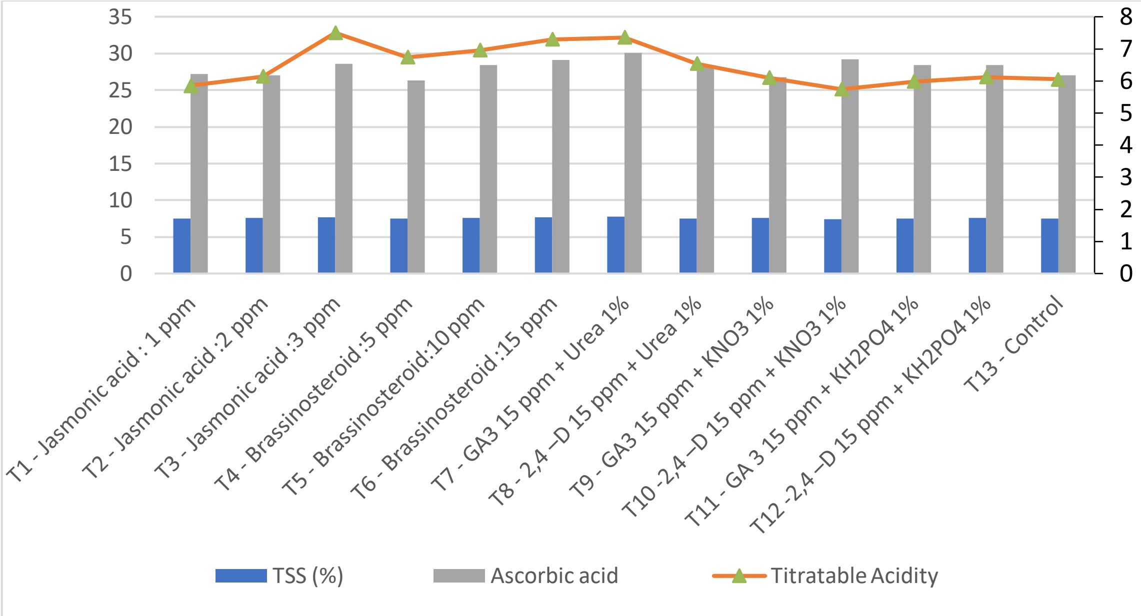

Fig. 4.10-Effect of crop regulating treatments on TSS, ascorbic acid and titratable acidity parameters of acid lime

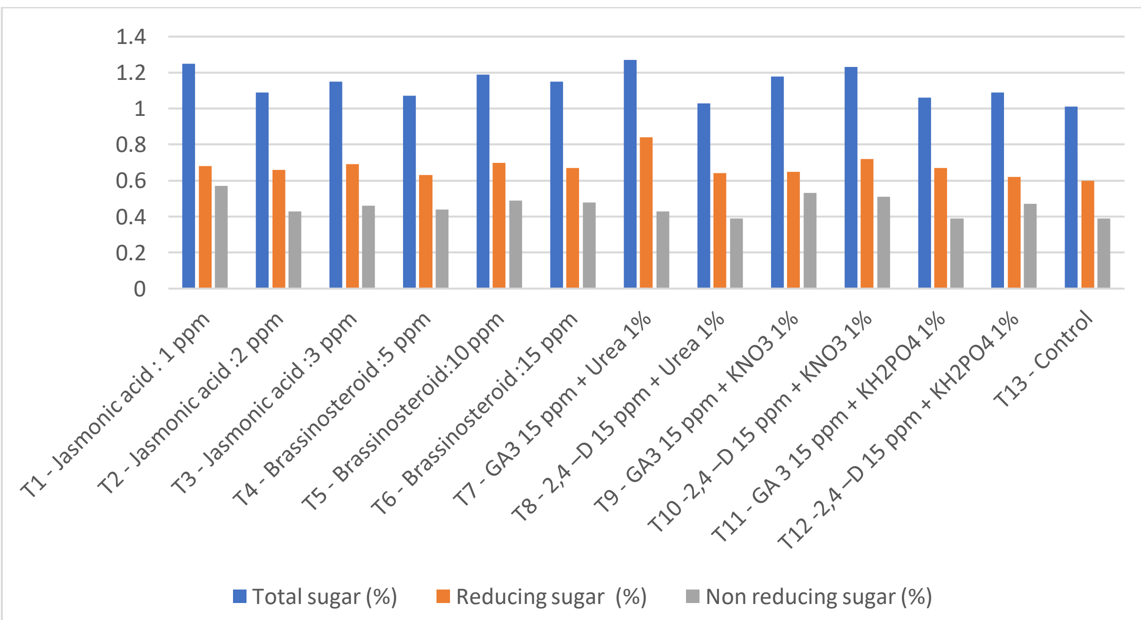

Fig. 4.11-Effect of crop regulating treatments on total sugars, reducing sugars and non- reducing sugars parameters of acid lime

CHAPTER V
SUMMARY AND CONCLUSIONS

An experiment entitled "Effect of foliar application of growth regulators and nutrients on fruit retention, yield and quality of acid lime (*Citrus aurantifolia* Swingle)" was carried out in Randomized Block Design (RBD) with three replication and 13 treatments, during 2019-2020, at ICAR-Central Citrus Research Institute, CCRI, Nagpur, (MH). The results obtained and discussed in the preceding chapter have been summarised below.

The important findings of the study on fruit retention, yield and quality characters are summarised below.

The application of growth hormones and nutrients at three consecutive months (February, March and April) in *Ambia bahar* significantly influenced the yield attributing characters of acid lime. Maximum fruit set (20.98 %) was recorded in treatment T_3 - Jasmonic acid @ 3 ppm whereas treatment T_{10} -2,4 –D @ 15 ppm + KNO_3 1% exhibited minimum fruit drop (37.88 %). Significantly maximum number of fruit plant^{-1}was recorded by treatment T_3-Jasmonic acid@ 3 ppm (1234), fruit weight (52.36 g) by treatment T_6-Brassinosteroid @15 ppm, and the maximum yield per plant (62.02 kg) and fruit yield (17.18t ha^{-1}) were recorded with the application of T_3-Jasmonic acid @ 3 ppm. However, the nutrient and growth hormonal combination T_{10}-2,4 –D @ 15 ppm + KNO_3 1% received the maximum (62.12 %) of fruit retention.

The data revealed that the maximum percentage (37.12 %) of fruit having weight 50-55 g (Grade A) was obtained in treatment T_3-Jasmonic acid @ 3 ppm, however in grade B maximum was recorded in treatment T_8-2,4 -D@ 15 ppm + Urea 1% and in grade C treatment T_4-Brassinosteroid @ 5 ppm showed the maximum percentage of fruits (48.27%).

However, the application of growth regulation treatments did not influence the no. of flowers per meter shoot length and directional fruit set. Although the treatmentT_5-Brassinosteroid @10 ppm obtained maximum no. of flower per meter shoot length (164.36), and maximum North-South direction fruit set (740) was found in treatment T_3 -Jasmonic acid @ 3 ppm, maximum fruit set (612.0) at the east-west direction was recorded in treatment T_7 - GA_3@ 15ppm + Urea 1%.

Application of T_3-Jasmonicacid @ 3 ppm in was more effective for physical characters such as fruit breadth, juice content and fruit volume. Although, T_7-GA_3 15 ppm + Urea 1% are more effective for fruit length and the minimum number of seeds fruit^{-1} (7.69) was found in treatment T_{11}-$GA_3$15 ppm + KH_2PO_4 1%.

Application of T_7-GA_3 15 ppm + Urea 1% is more effective for quality characters namely TSS, ascorbic acid, total sugar and reducing sugar. Although, T_3-Jasmonic acid @ 3 ppm in notably influence the titratable acidity. However, non-reducing sugar was found statistically non-significant.

Conclusion

Foliar application of T_{10}- 2,4-D @ 15 ppm + KNO_3 1% notably reduced fruit drop and enhanced fruit retention which significantly contributed to final fruit retention and fruit yield.

The foliar spray of T_3-Jasmonicacid @ 3 ppm in February, March and April in acid lime enhanced yield attributing fruit characters such as fruit set %, no. of fruits plant^{-1}, fruit breadth, fruit volume and titratable acidity, which ultimately increased yield plant^{-1}. The application of GA_3 @ 15 ppm + urea 1% increased the fruit length, no. of seeds/fruit, TSS, ascorbic acid, total sugars, reducing sugars whereas T_6-Brassinosteroid @ 15 ppm recorded maximum fruit weight.

The extent of premium marketable fruits expressed as the graded yield of acid lime in fruit weight classes A, B, C was recorded maximum in T_3-Jasmonic acid @ 3 ppm, T_6-Brassinosteroid @15 ppm and T_7-GA_3 @ 15 ppm + urea 1% respectively.

CHAPTER V

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APPENDIX-A: Meteorological observations recorded during experimentation at Nagpur district (September 2019- April 2020)

Wk. No.	Date	Max. Temp (ºC)	Min. Temp. (ºC)	Rainfall (mm)	Rainy days	Relative Humidity (%)		Vapour Pressure (mm of Hg)		Wind Velocity (Kmph)	Evaporation (mm)	Sun Shine (hours)
						I	II	I	II			
1	**27 – 02**	31.43	23.73	110	2	94.07	28	7.9	7.3	0.7	16.8	6.6
2	**03 Sep –09**	28.74	23.74	150.3	3	94.43	21	8.9	8.7	0.9	16.5	6.1
3	**10 – 16**	29.31	24.51	27.6	5	92.43	21	7.8	53.2	0.9	18.7	6.8
4	**17 – 23**	32.27	25.17	82.7	7	91.57	53	11.1	11.2	2.0	18.5	4.0
5	**24 – 30**	31.53	23.10	74.1	6	91.14	24	8.3	6.4	1.3	20.6	8.2
6	**01 Oct – 07**	33.34	22.56	4.90	2	78.71	36	9.9	9.2	1.5	21.3	7.6
7	**08 – 14**	33.39	20.80	0.00	0	75.43	34	11.0	10.0	1.8	20.4	8.3
8	**15 – 21**	31.44	21.29	9.80	3	84.71	30	12.6	11.3	1.7	30.3	9.1
9	**22 – 28**	30.31	20.81	49.20	4	84.14	36	11.8	11.3	12.4	30.7	7.8
10	**29 – 04**	32.54	21.16	1.00	2	83.43	32	11.8	11.7	2.4	40.3	8.9
11	**05 Nov – 11**	31.00	14.81	0.00	0	78.14	33	15.0	13.5	8.3	36.7	6.8
12	**12 – 18**	31.00	14.81	0.00	0	78.14	28	15.5	11.2	2.4	37.1	8.4
13	**19 – 25**	31.91	14.91	0.00	0	86.43	19	13.4	10.5	2.0	44.5	8.7
14	**26 – 02**	29.39	12.51	0.00	0	75.86	18	13.2	9.8	3.4	53.2	8.3
15	**03 Dec – 07**	24.04	12.73	50.20	3	72.14	32	11.8	15.7	2.4	40.3	8.9
16	**08-15**	29.06	15.74	3.70	1	68.12	33	15.0	13.5	8.3	37.6	6.8
17	**16-23**	28.93	13.96	0.00	0	59.36	30	18.5	11.2	2.4	37.1	8.4
18	**24-31**	28.93	13.96	0.00	0	79.24	19	13.4	10.5	2.0	44.5	8.7
19	**01 Jan-07**	24.89	11.17	50.20	3	87.57	18	13.2	9.8	3.4	53.2	8.3
20	**08 – 14**	26.46	9.74	7.30	1	87.29	27	15	13	5.1	54.4	9.0
21	**15 – 21**	26.99	14.10	0.00	0	82.71	15	14.1	9.3	2.9	59.6	10.1
22	**22 – 28**	30.17	14.19	0.3	1	82.71	26	18.1	13.7	4.1	56.4	8.2
23	**29 – 04**	26.91	13.91	0.6	1	77.86	12	12.0	13.7	2.6	68.0	9.3
24	**05 Feb – 11**	24.87	13.33	13.7	3	84.29	15	13.5	9.5	3.4	74.1	10.3

25	**12 – 18**	31.60	12.64	0	0	68.29	18	15.7	11.3	5.1	79.5	9.8
26	**19 – 25**	32.59	16.50	0	0	73.00	28	18.4	14.7	5.9	76.3	7.8
27	**26 – 04**	33.26	14.93	0	0	68.86	27	20.4	17.6	5.2	67.6	6.2
28	**05 – 11**	33.69	17.99	0	0	62.00	32	20.4	18.9	8.2	75.7	7.8
29	**12 – 18**	33.77	19.60	6.2	2	69.57	54	22.9	20.5	6.7	41.3	4.6
30	**19 – 25**	36.30	18.14	2	1	69.86	53	22.7	22.1	59	39.0	5.0
31	**26 – 01**	36.43	21.00	4.8	2	61.00	84	22.1	23.4	11.0	16.6	1.2
32	**02 Apr – 08**	37.21	21.47	0.00	0	54.14	59	22.1	22.5	8.9	39.1	3.6
33	**09– 15**	40.73	22.03	0.00	0	48.43	55	23.5	22.0	4.5	36.3	3.6
34	**16 – 22**	41.17	23.59	0.00	0	44.43	77	23.2	24.4	6.3	25.3	7.5
35	**23 – 29**	40.61	22.33	7.70	0	51.29	82	21.2	23.1	11.2	14.5	2.7
36	**30 – 06**	42.73	24.10	1.50	1	49.14	83	22.8	23.6	11.1	22.5	1.2

VITA

Name	:	**Yamini Sapaha**
Father's name	:	Mr. Kishan Sapaha
Date of Birth	:	28/12/1996
Nationality	:	Indian
Permanent Address		At/Po- Mohgaon, Via- Saja,
		Dist. – Bemetara, Chhattisgarh, PIN – 491993

Academic Qualifications:-

Degree	year	University/ Institute
12^{th}	2014	CG Board Raipur,Chhattisgarh
B.Sc. (Ag.)	2018	IGKV, Raipur,(CG)
M.Sc.(Hort.)	2020	IGKV, Raipur,(CG)

Training Experience : RAWE (Rural Agricultural Work Experience)

Ysapaha

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